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BASAL METABOLISM OF GIRLS

PHYSIOLOGIC BACKGROUND AND APPLICATION OF STANDARDS

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BOSTON

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Summary

INTRODUCTION

There has been a tremendous increase in interest in basal metabolism during the past twenty years owing to the fact that this measurement has become of clinical importance and of great practical benefit. The development of portable machines which can be operated with little training has made it possible for large numbers of physicians to make the test. It is estimated that 10,000 portable apparatus are in use in this country. "The result has been an enormous number of experiments, most of them with poor technic" (Du Bois).[1]

After the metabolism of a number of normal persons had been studied, various standards were developed with which it was proposed to compare the metabolism of persons with pathologic conditions. The standards used for adults have apparently worked out satisfactorily, for the investigators of metabolism in adults have been content with them. It was different, however, with the study of metabolism during childhood, which is a period of constant change and development. The standards were fairly complete for persons of both sexes up to puberty,

1. Du Bois, E. F.: J. Nutrition **3**:217, 1930.

but few normal persons had been studied carefully from puberty to the age of 20 years. Some of the gaps were filled in by various workers, but blank spots which needed more study remained. With this in view, we obtained the metabolism of 106 healthy normal girls attending a private school in Boston. The observations were subjected to severe tests for normality and basality, and when all the desired information was recorded they were used in group studies in this paper.

Our second purpose in the study was to clear up a problem which has long troubled competent clinicians. These workers had little trouble in interpreting the metabolism of normal persons, but a comparison of the metabolism of many patients with pathologic conditions with the various available standards either gave inconsistent findings, such as a normal value by one standard and a very low one by another, or led to clinical conclusions which were not substantiated by subsequent treatment. This was all confusing, and it was decided about fifteen years ago to apply all standards then available to every case of pathologic change studied and to check results later by means of therapeutic tests and clinical progress. As a result of this procedure over a period of ten years, the conclusion was reached that all standards worked satisfactorily with normal persons whose weight was close to the average weight for the height but that with abnormal persons the use of a standard based on total calories for weight gave the most accurate picture of the clinical status of the patient. The use of this standard in diagnosis and treatment resulted in fewer mistakes than that of any other standard. This circumstance was modified in certain conditions, which were discussed in a previous paper.[2]

This clinical experience suggested the thought that it might be possible to gather all the original data that had been previously published on the metabolism of girls, compare them with the new data and subject them to mathematical analysis. Although individual studies had been analyzed mathematically, no such analysis of all the known data had been made by one person. In some publications the original data gave most of the material desired, but many of them contained only statements of plus or minus variations or averages, which were valueless for our purpose. In these instances we wrote to the various workers, explained our purpose and were given the original data needed. We also had the privilege of looking over the original kymographic records in some instances. Some of the authors went through their records and

2. Talbot, F. B.: J. Pediat. **3**:247, 1933.

copied tables for us in longhand, and others freely gave us new and unpublished data. As we were unable to see Boothby's data, they cannot be considered here. Dr. William Palmer Lucas and Dr. Marion E. Stark gave us free use of their unpublished data, and Prof. A. T. Cameron, Miss E. M. Bedale (Mrs. Wishart), Prof. Itsiro Nakagawa, Prof. Hidea Takahira, Dr. Ellen M. Hindmarsh and Dr. George R. Klugh made available unpublished original data.

During the course of this investigation the emphasis was placed on studies of normal persons to determine whether there was any justification for the use of total calories for weight as a standard. Further consideration was given to the persons whose ratio of weight to height fell outside the limits generally accepted as normal, to learn how their metabolism was affected by loss of weight or by excessive fat. It was felt that the influence of these factors should be taken into account in any normal standard. (The Baldwin-Wood standard of height and weight was used, not because it is preferable to other standards but because it had been used in all earlier publications. The limits of normality were — 10 per cent and + 20 per cent.)

BOSTON PRIVATE SCHOOL GROUP

The metabolism of this group of children was determined through the permission of a private school and with the approval of the parents. Tests were started in February 1932 and finished in May 1932, with some exceptions; 106 children were tested, but some results were eliminated because repeated attempts did not give what we considered basal figures. (The child would not remain quiet or had too high a pulse rate or an irregular kymographic curve.)

The children were all from well-to-do families; their hygienic background and opportunities were excellent. Some were under the average weight for their height, and a few were stout. They represented a characteristic cross-section of the typical private school population in New England.

Table 1 shows the values for heat production and other data found for this group of girls.

TECHNICS OF VARIOUS AUTHORS

Since the technic used by the various authors is not described in detail in all the reports, it seemed wise to collect this information, so that when any set of material is considered the methods of selecting the data can be referred to.

The material in table 2 was sent to us, and some of it has never before been published. It may be seen that the general point of view of all the investigators is similar and that they differ only in details. Most of the methods of selecting data follow in general the suggestions of Francis G. Benedict, who has been criticized for taking the periods yielding the lowest results. What differences there are in the technic used seem to us insignificant when compared with the possible difference in the reactions of the subjects themselves. There is little doubt that most of the investigators, and especially those who know and understand children, have taken this into consideration, but it might have received greater emphasis. It was the first consideration with our own group. All clinical observations were checked first by the pulse rate and second by the character of the kymographic curve. When these indicated that the period might not be basal, it was eliminated. If the period passed the clinical test, the test of checking within 5 per cent was applied, and the values for satisfactory periods were averaged and used. So far as one can read between the lines, Stark approached the problem from the same point of view, and probably others did.

ARRANGEMENT OF THE ANALYSIS

With respect to the arrangement of our contribution, it seemed wise to divide the analysis into two parts, one chiefly statistical and the other chiefly clinical. This procedure was adopted for several reasons.

First, the mode of attack, even to the method of composition, which is most convenient for one group of readers and investigators is decidedly not most satisfactory for another. This is especially so when the two groups differ as much in method and in point of view as do the biostatisticians and the clinicians. Although our chief aim has been to make easier a combination of the two points of view, it seemed that a dual treatment, first from one and then from the other aspect, would lay the basis for such a synthesis better than a single treatment in which statistical and clinical aspects were constantly intermingled.

Second, although for the rational discussion of the significance of measurements the difficult even-handed synthesis of statistical and clinical points of view has become indispensable, it must be admitted that the statistical method is designed to deal with, to describe and to compare groups and to determine scientific differences that may exist between groups of men and women, northern or southern residents and so on. The problem of the clinician is, however, to interpret the situation of an individual. For this interpretation he has available a large amount of material, of the nature of a case history which is not available to the

TABLE 1.—*Data on Boston Private School Girls* *

Girls Within +20 and —10 per Cent of Normal by the Baldwin-Wood Height-Weight Standard

Case No.	Date	Age Yr.	Age Mo.	Weight, Kg.	Height, Cm.	Total Calories	Pulse	Temperature, F.	δWeight	δHeight†
2	March 1932	10	6	41.0	151.7	1,344	69	98.2	7.5	9.9
4	Feb. 1932	10	11	37.3	148.3	1,250	69	98.4	3.5	9.6
5	April 1932	11	1	33.6	143.7	1,140	76	98.4	—0.5	6.1
6	June 1932	11	6	44.4	153.7	1,516	76	97.8	6.5	6.1
6	June 1933	12	6	55.6	160.0	1,519	76	98.2	...	...
7	March 1932	11	4	62.0	163.3	1,577	73	98.0	9.9	7.6
9	Feb. 1932	11	5	33.3	140.5	1,358	70	98.6	6.6	6.1
10	Feb. 1932	11	5	40.2	145.5	1,197	76	98.6	5.0	6.4
11	March 1932	11	6	41.8	150.5	1,713	68	97.8	7.4	6.9
11	May 1932	11	8	43.8	152.7	1,696	81	97.6	...	...
12	Feb. 1932	11	6	47.7	151.2	1,219	74	98.6	6.4	5.8
13	April 1932	11	9	57.6	167.5	2,140	92	98.8	7.3	27.4
13	April 1933	12	9	64.5	174.0	1,618	70	98.6	...	...
14	Feb. 1932	11	9	48.0	157.0	1,267	66	98.0	5.5	4.4
15	Feb. 1932	11	9	34.7	135.2	1,303	74	98.0	7.3	9.1
17	Feb. 1932	11	11	41.7	151.2	1,392	90	98.0	2.7	5.3
18	March 1932	12	2	39.2	149.3	1,430	71	98.6	4.5	5.8
19	Feb. 1932	12	2	36.0	141.2	1,180	84	98.0	5.3	4.4
20	March 1932	12	3	46.0	158.5	1,454	82	98.6	5.2	6.9
21	Feb. 1932	12	3	43.7	151.5	1,442	63	98.4	9.9	7.0
23	Feb. 1932	12	6	50.0	153.7	1,413	80	98.0	4.8	7.6
24	Feb. 1932	12	7	43.8	152.7	1,245	76	98.0	2.7	5.6
26	March 1932	12	11	48.7	160.5	1,665	77	97.8	—3.0	5.3
27	May 1932	13	0	50.6	158.2	1,456	69	98.2	7.9	7.2
28	March 1932	13	1	53.1	164.7	1,605	62	97.8	...	...
30	Feb. 1932	13	7	57.5	158.2	1,442	84	98.6	4.6	2.1
33	March 1932	13	10	52.8	160.5	1,548	86	97.8	—4.3	2.6
35	March 1932	13	11	48.5	160.7	1,509	73	98.0	5.3	4.8
36	April 1932	13	5	52.2	165.2	1,243	74	98.6	2.0	4.3
37	April 1932	13	6	50.6	161.5	1,413	61	97.8	3.1	4.4
40	March 1932	14	2	53.0	160.2	1,507	80	97.6	7.0	2.6
42	March 1932	14	7	49.4	163.5	1,660	77	97.8	4.3	4.2
43	March 1932	14	11	51.0	164.5	1,447	74	98.0	...	...
44	May 1932	14	5	52.1	162.5	1,406	68	98.2	2.1	2.2
45	April 1932	14	6	46.1	154.5	1,377	78	98.6	2.3	2.0
47	May 1932	14	7	62.9	162.0	1,507	77	97.8	0.9	1.2
48	April 1932	14	9	56.0	157.0	1,766	88	98.0	7.1	6.4
49	April 1932	14	9	56.8	171.0	1,651	79	97.8	0.9	2.3
50	May 1932	14	3	53.0	160.7	1,216	75	97.8	3.5	2.6
51	June 1932	14	3	57.1	159.6	1,305	70	97.8	0.3	1.3
53	March 1932	15	..	49.0	160.2	1,416	68	97.4	2.5	2.3
54	Oct. 1931	15	..	59.5	168.1	1,332	76	98.6	5.0	0.3
54	Dec. 1932	16	..	63.4	170.8	1,426	80	97.8	...	...
55	Feb. 1932	15	11	52.8	165.5	1,438	87	98.6	2.3	1.7
56	May 1932	15	..	62.7	169.5	1,461	69	97.8	3.8	0.9
57	April 1932	15	..	62.7	169.5	1,464	74	98.2	—0.6	0.5
58	May 1932	15	1	61.1	171.0	1,574	76	98.2	3.2	1.5
59	April 1932	15	1	55.5	164.2	1,497	66	98.0	0.2	1.8
61	April 1932	15	4	54.0	161.5	1,392	83	98.0	4.2	2.0
62	May 1932	15	5	61.0	168.7	1,569	78	98.2	2.5	0.9
63	May 1932	15	5	57.7	161.0	1,404	78	97.8	...	...
64	April 1932	15	6	49.0	161.5	1,300	66	98.0	2.7	2.5
65	April 1932	15	6	67.5	178.5	1,665	81	98.4	6.9	1.8
66	May 1932	15	11	54.0	165.5	1,236	54	97.2	2.2	1.5
67	May 1932	15	11	61.7	169 2	1,459	72	98.6	0.6	1.3
68	May 1932	16	..	60.7	165.5	1,416	68	97.8	2.3	2.5
69	March 1932	16	3	62.0	172.0	1,792	86	98.2	—1.7	1.8
70	May 1932	16	..	56.1	161.2	1,243	72	97.8	1.3	1.3
72	May 1932	16	2	63.1	164.7	1,512	70	97.8	3.8	2.0
73	May 1932	16	2	58.3	165.0	1,573	68	97.8	0.0	2.5

* The determinations of metabolism were made by Miss Ebba C. Blomquist, R.N. The portable apparatus used was supplied by Warren E. Collins, Inc.

† The entries δ weight and δ height are the increase in weight expressed in kilograms and the increase in height expressed in centimeters for the year from September 1931 to September 1932. The metabolic tests were made in approximately the middle of this period.

TABLE 1.—*Data on Boston Private School Girls—Continued*

Case No.	Date	Age Yr.	Age Mo.	Weight, Kg.	Height, Cm.	Total Calories	Pulse	Temperature, F.	δWeight	δHeight
74	May 1932	16	2	58.8	169.0	1,533	69	98.2	2.4	3.0
75	May 1932	16	2	54.7	164.0	1,423	74	97.8	2.3	1.2
76	May 1932	16	3	62.6	162.7	1,970	78	97.8	—1.4	0.3
77	May 1932	16	3	54.1	163.0	1,540	78	98.6	...	...
78	April 1932	16	4	59.6	163.5	1,531	68	98.4	0.4	0.5
79	May 1932	16	6	63.9	163.2	1,593	66	98.0	...	...
81	May 1932	16	7	56.9	164.0	1,293	68	97.8	...	...
82	May 1932	16	8	60.1	172.7	1,404	55	97.8	...	...
83	May 1932	16	9	63.7	166.2	1,502	66	97.8	...	...
84	April 1932	16	9	67.0	185.2	1,552	82	98.6	...	...
86	May 1932	16	11	47.2	156.7	1,255	80	98.6	...	...
89	March 1932	17	9	55.9	168.3	1,644	74	98.4	...	...
90	April 1932	17	1	64.9	170.5	1,656	66	98.0	...	...
92	April 1932	17	2	58.7	159.2	1,677	67	98.2	...	...
93	April 1932	17	5	60.7	168.7	1,504	67	97.8	...	...
94	April 1932	17	5	62.2	167.2	1,581	65	98.0	...	...
95	May 1932	17	6	50.9	158.5	1,336	70	97.8	...	...
96	May 1932	17	7	56.5	168.5	1,269	54	97.8	...	...
97	May 1932	17	8	54.2	167.7	1,291	58	97.4	...	...
98	May 1932	17	8	52.6	160.5	1,497	60	97.6	...	...
99	April 1932	17	8	49.4	161.7	1,329	74	98.0	...	...
100	April 1932	17	9	61.0	165.0	1,377	74	98.4	...	...
100	Nov. 1933	19	4	63.1	166.4	1,406	63	97.8	...	...
101	May 1932	17	..	82.1	184.2	2,152	69	98.6	...	...
102	March 1932	18	..	56.0	164.5	1,564	73	98.0	...	...
103	April 1932	18	4	57.5	163.2	1,305	63	98.2	...	...
105	April 1932	18	6	58.0	159.7	1,353	74	98.0	...	...
106	May 1932	18	7	57.9	161.0	1,327	67	98.4	...	...
107	May 1933	10	11	42.4	149.3	1,195	66	97.6	...	...
				Underweight Girls						
1	Feb. 1932	10	3	28.5	138.5	1,270	89	98.6	4.3	6.0	—13
8	Feb. 1932	11	5	29.4	138.5	1,265	80	98.6	...	...	—10
16	March 1932	11	11	35.2	151.5	1,221	86	98.6	4.3	5.8	—18
25	March 1932	12	7	36.6	150.0	1,317	71	98.0	4.1	6.1	—11
29	March 1932	13	5	42.3	155.5	1,392	92	98.6	1.3	4.0	—10
34	March 1932	13	10	30.4	147.5	1,284	73	97.8	5.8	8.2	—22
38	March 1932	14	..	48.0	170.7	1,516	79	98.8	...	...	—20
39	April 1932	14	..	44.7	162.5	1,365	76	98.4	...	...	—16
104	April 1932	18	4	48.1	165.7	1,231	85	98.0	...	...	—13
				Overweight Girls						
3	Feb. 1932	10	10	44.6	144.3	1,502	69	98.2	7.9	10.1	21
22	Feb. 1932	12	6	62.9	160.5	1,622	74	98.2	2.1	2.8	24
31	March 1932	13	8	95.0	173.0	1,901	73	98.0	5.0	2.3	35
32	March 1932	13	10	59.7	149.7	1,630	75	98.6	—0.9	6.6	44
46	April 1932	14	6	76.3	176.2	1,668	75	98.0	5.3	3.2	21
52	June 1932	14	3	60.8	158.7	1,509	82	98.0	—3.3	1.8	21
60	April 1932	15	2	69.4	164.0	1,550	76	97.8	3.4	1.5	27
71	April 1932	16	1	75.8	164.2	1,608	77	98.0	3.0	2.2	39
80	May 1932	16	6	65.6	162.0	1,317	74	98.6	...	...	24
85	May 1935	16	10	66.1	164.0	1,543	76	98.0	...	...	22
87	March 1932	17	0	59.0	157.0	1,337	73	98.6	...	...	21
88	March 1932	17	6	66.6	164.0	1,757	69	97.6	...	...	22
91	May 1932	17	2	61.3	157.5	1,392	53	97.8	...	...	24

statistician and which, if available to him, might not readily be incorporated into a statistical treatment. In other words, the clinician has available for his interpretation a different body of material from that of the statistician. Owing to this difference, the conclusions which are of importance to the statistician and those of significance to the clinician overlap only in part; in part they may, in the present state of the knowledge of each, actually be discordant.

TABLE 2.—*Apparatus and Methods of Selecting Data for Publication Used by Various Authors*

Author	Apparatus	Soda Lime	Selection of Figures for Publication
McKay	Benedict-Roth (Warren E. Collins)	Wilson soda lime; correction factor given on chart	"We used the lower figure for each day on which we found satisfactory checks and averaged these lower figures;" sometimes averaged lower figures of three days; days without satisfactory checks and when subjects were not in basal condition discarded
Coons	Benedict-Roth (Warren E. Collins)	Wilson soda lime; 15-19% moisture; 5% alkali; correction factor given in booklet of instructions	Averaged 2 determinations agreeing within 5%; if kymograph or other notations indicated some condition not conducive to basal conditions, only lowest figures used; in most cases the test was made on only one occasion; data therefore on untrained subjects; lowest figures not used if subject fell asleep
Lucas (Helen B. Pryor)	Benedict-Roth (Warren E. Collins)	Wilson soda lime; no correction for tension of aqueous solution	Two lowest periods which checked within 4% were used
Cameron	Sanborn-Handy and in few cases Sanborn-Benedict	Sanborn soda lime; no correction, since it was supposed to have been made by Sanborn	Made 15 minute tests; minute readings mean figures; 2 minute averages made and discrepant readings rejected; lowest reading not selected unless the reading selected on other grounds happened to be lowest
Topper	Benedict-Roth (Warren E. Collins)	Sansolime; 15-18% moisture; no correction for tension aqueous solution	All figures were lowest readings; "two tests made at one sitting and the lowest reading taken provided there was no more than 5% difference between the 2 readings; should the difference exceed 5% the tests were discarded and taken again as soon as possible"
Remington	Benedict-Roth (Warren E. Collins)	Wilson soda lime; made 2 blank tests to obtain saturation	Three determinations on each subject on three successive days; twelve minute tests; selected the six minute portion of the curve "which in our judgment gave the lowest and most uniform slope"
Blunt	Benedict Portable, (an early Sanborn, Warren E. Collins, or Roth)	Wilson soda lime; Roth apparatus 2% correction made	Observations on 2 days close together; "if they agreed within 5% the average figure was called the basal metabolism; if agreement was not so good it was decided to take as basal the 2 lowest periods of the two days if these checked;" in a few cases, when the oxygen consumption was consistently higher on the first than the second day, only the second day's values were taken
Nakagawa	Benedict Cot-Chamber	Soda lime made in Japan; no correction	Average two periods each of 30 minutes; if they varied more than 5% they were discarded
Stark	Sanborn-Benedict	Wilson soda lime; 2% correction for water vapor at 21 C. incorporated in calibration of charts used with Sanborn apparatus	"I always used the lowest period among duplicate runs constituting any one test on a given person on a given day; any runs that were discarded altogether were thrown out because of obvious faults, either in the technical conduct of the test, the character of tracing, or the behavior of the patient"
Morgan	Sanborn-Benedict	Wilson soda lime; "I am under the impression that the corrections suggested by Roth were made for aqueous water saturation"	"All the data we collected were published and none was rejected; each figure given represents the average of from 2 to 4 determinations on the same subject in a given morning and checked within 3% of his average; a good deal of preliminary practice was undertaken to obtain complete relaxation and good cooperation"

TABLE 2.—*Apparatus and Methods of Selecting Data for Publication Used by Various Authors—Continued*

Author	Apparatus	Soda Lime	Selection of Figures for Publication
McLeod	Sanborn-Benedict	Sanborn supplied first soda lime from army and then Wilson; soda lime treated as saturated with vapor and corrected from average room temperature to 0 C. 760 mm.	Two tests each morning, and always two days in close succession; periods which checked within 5% were used for averages from which the basal metabolism was recorded
Tilt	Sanborn-Benedict	Wilson soda lime; factors for reducing volume of 80% saturated air to 0 C. dry and 760 mm. were obtained from correction tables using R. E. Wilson's formula (Boston M. & S. J. **187**: 133 [July] 1922)	"Observations were made on two days as close together as possible; if all the observations on these two days agreed within 5% the average was called the basal metabolism; if the agreement was not so good, a third test was made if possible; if not, the lowest periods of two days were taken if they checked"
Bedale 1919-1921	Haldane Portable	"Usual solutions"	"Large number of experiments discarded; I believe it was nearly 10% among the oldest of my boys and girls because they were impossibly low; because of these low values the possibility of imperfect collections leaves one without confidence in the findings and I came to regard the basal metabolism observations as quite the weakest part of the paper on child nutrition"
Wang	Benedict Cot-Chamber universal respiratory apparatus	Haldane soda lime; no correction; alcohol checks used	"We used the two lowest figures in a series of not less than 6 tests of metabolism on each child; usually we had to make more than 6 tests"
Talbot	Benedict-Roth (Warren E. Collins)	Wilson soda lime; corrected for aqueous saturation	Only periods used which checked within 5%; no data considered if the child did not appear to be in a clinically basal condition or had an elevated pulse rate; periods discarded for which the kymographic curve was not regular; the lowest figures which were within 5% of each other were averaged; 3 tests of six minutes each day

The arrangement that has been adopted is to follow this general introduction with a statistical analysis and then with a clinical discussion. We hope that with the aid of numerous cross-references we shall have succeeded in making the two parts more available to the investigators especially interested in each without handicapping those who are interested, as we are, in working out a real synthesis of the two points of view so far as a common body of data is available for both.

STATISTICAL ANALYSIS

1. BASIC SERIES OF DATA

Such statistical aspects of the basal metabolism of normal girls as may aid in determining standards for clinical use will be discussed. It is particularly desirable to set up standards based on height and weight separately. The statistical problem thus set is difficult because of (1) the

paucity of data for the age range from birth to 8 years,[3] (2) the absence of data over long consecutive age ranges for the same persons [4] and (3) the nonlinearity of the relationships between the variables [5] age (A, expressed in years), weight (W, expressed in kilograms), height (H, expressed in centimeters) and basal metabolism (C, expressed in calories per day).

Considerable data are available in the literature and in unpublished sources for the age range of from 8 to 20 years. After careful consideration it was decided to use for the primary discussion on the series of Benedict and Talbot [6] and the series of Talbot (published in this paper) of 87 measurements on 85 girls in a private school and to discuss the other determinations in relation to these as a base.[7]

It might be possible to take such functions of the variables as would render the relationships linear, and it would be desirable to do so if other desired statistical objectives could be simultaneously attained. Trial showed that a high degree of linearity could be had by plotting (1) basal metabolism, C, against $\sqrt{W/H}$ or (2) the logarithm of $C + 1{,}000$ against log (W/H), viz,

$$C = 4{,}128 \sqrt{\frac{W}{H}} - 918 \qquad (1)$$

or

$$\log (C + 1{,}000) = 0.47 (\log \frac{W}{H} - 0.69) - 3.335. \qquad (2)$$

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3. The only systematic data for this range are the 75 measurements of Benedict and Talbot on 41 girls under 8 years old.

4. In the various studies on growth in which the same subjects were observed over a considerable period of years, as is necessary in studying processes of growth, the basal metabolism, important as its determination and discussion are, has not been reported; the expense involved and the special equipment and services necessary for its determination seem to have precluded its study during growth.

5. The Harris-Benedict formulas are linear regression equations giving C in terms of W, H and A, but applicable only at ages from 20 years on. They give impossible values for C when extrapolated backward into the age range of interest to the pediatrician.

6. Benedict, F. G., and Talbot, F. B.: (*a*) The Physiology of the New-Born: Character and Amount of the Katabolism, Publication 233, Carnegie Institution of Washington, 1915; (*b*) Metabolism and Growth from Birth to Puberty, Publication 302, Carnegie Institution of Washington, 1921.

7. That there are differences in different series of data (whether due to climatic conditions, to experimental technic, to socio-economic status, to seasonal variability, to differing racial origins or to other variables) can readily be verified by plotting almost any two considerable series for comparison. Although it cannot be maintained that the Benedict and Talbot and the Talbot series have all these variables under control, it was thought best to use for the base those observations in which Dr. Talbot had been personally concerned, which covered the entire age ranges of interest to the pediatrician and which were made in one locality on girls individually well known to the observer.

The standard deviation of C from regression line (1) was 68 for the Benedict and Talbot series (coefficient of variation, 11.8 per cent) but was 167 (coefficient of variation, 11.4 per cent) for the private school group—or 131 for the entire group. It is observable that the coefficient of variation is the same for the two groups, i. e., that the errors of fit are proportional rather than absolute. Somewhat similar results could be obtained for regression line (2). It is not to be supposed that such empirical fittings are anything more than empirical.[8] The same may be said of the linear regressions of Harris and Benedict[9] on W, H and A.

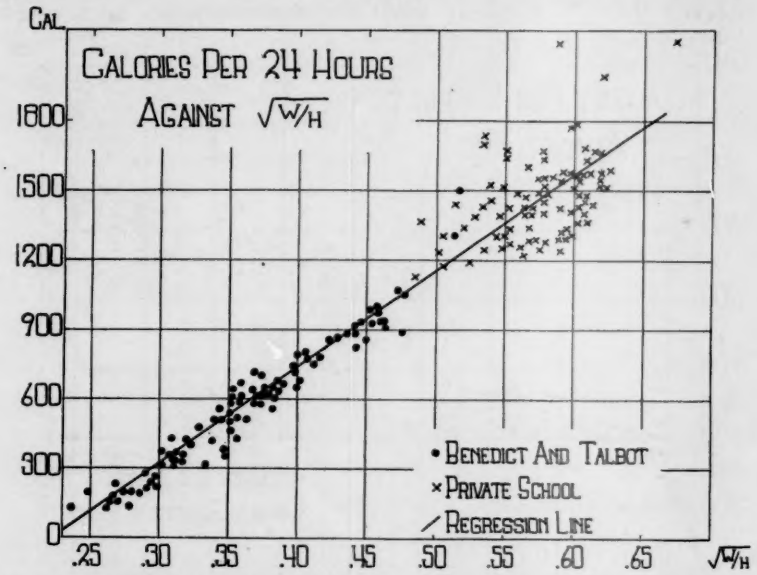

Fig. 1.—Scatter diagram of calories per twenty-four hours against the square root of the quotient of weight to height for the 179 observations of the basic series divided into the two parts: (1) Benedict and Talbot group and (2) private school (Talbot) group showing rectilinearity of the regression.

8. N. C. Wetzel has attempted a rational mathematical development of the relation between basal metabolism (C) and age in a series of papers "On the Motion of Growth," of which the eighth can be found in the Proceedings of the National Academy of Sciences (**20**:183, 1934). There has been considerable discussion of body surface as a rational basis for heat production, but no definite proof has been offered (see Du Bois, E. F.: J. Nutrition **3**:217 and 331, 1930). In the present state of our knowledge, whether theoretical or experimental, it is too much to hope that a treatment of basal metabolism suited to clinical uses can be based on rational considerations.

9. Harris, J. A., and Benedict, F. G.: A Biometric Study of Basal Metabolism, Publication 279, Carnegie Institution of Washington, 1919, p. 190.

2. USE OF LOGARITHMS

A plot of calories against age, weight or height (fig. 2) shows that the variation between persons is more or less proportional to the number of calories produced; moreover, it is customary to express deviations for individual subjects from the various standards in terms of percentages of the standard figures. These facts suggest that statistical work should be done on the logarithm, c, of the heat production rather than on the heat production, C, itself. Moreover, the diagram for weight against height seems distinctly less linear than that for log W against log H, and furthermore the Du Bois surface formula, $S = KW^{0.425}H^{0.725}$, is linear when the three variables are expressed

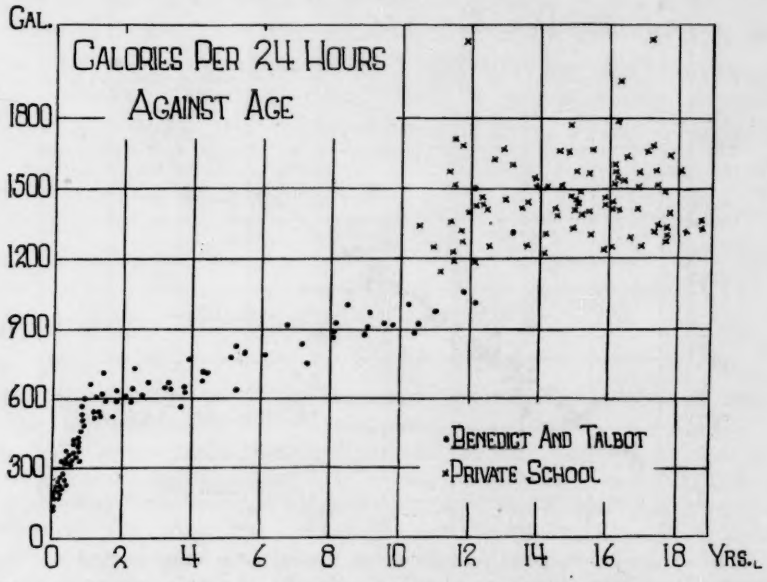

Fig. 2.—Scatter diagram of the basic 179 observations for calories per twenty-four hours against age showing the nonrectilinearity of the regression.

logarithmically. These facts suggest the choice of the logarithms of C, W, H and S as the fundamental statistical variables rather than C, W, H and S themselves. We shall use the small letters c, w, h and s for the logarithms (to the base 10) of the variables C, W, H and S.

A linear fit of log C to log W and log H for the basic 179 measurements gave [10]

$$\log C = 0.300 \log W + 0.876 \log H + 0.719. \qquad (3)$$

10. The calculations (by machine) were carried to 7 places, which should make them good to 5 or 6 places. The equation cited was carried down from log C = 0.299855 log W + 0.876208 log H + 0.71932. There seems to be no use in giving more than three places in the text; the maximum error thus introduced in the computed value of C is only 0.5 per cent, which is much less than its error of measurement.

The 179 residuals (log C as observed less log C as calculated) from (3) were plotted against age (A), against log W and against log H, and systematic deviations were shown in all diagrams. The standard deviation of the (logarithmic) residuals was 0.0640, corresponding to an error of 16 per cent, which is larger than that obtained from the empirical equation (1) for C in terms of $\sqrt{W/H}$, besides containing systematic errors. When a free hand curve was drawn to the residuals of the curve of c = log C against age (fig. 3), corrections for age could be found graphically and when applied gave a residual logarithmic standard deviation of 0.0407, corresponding to an error of 10 per cent,

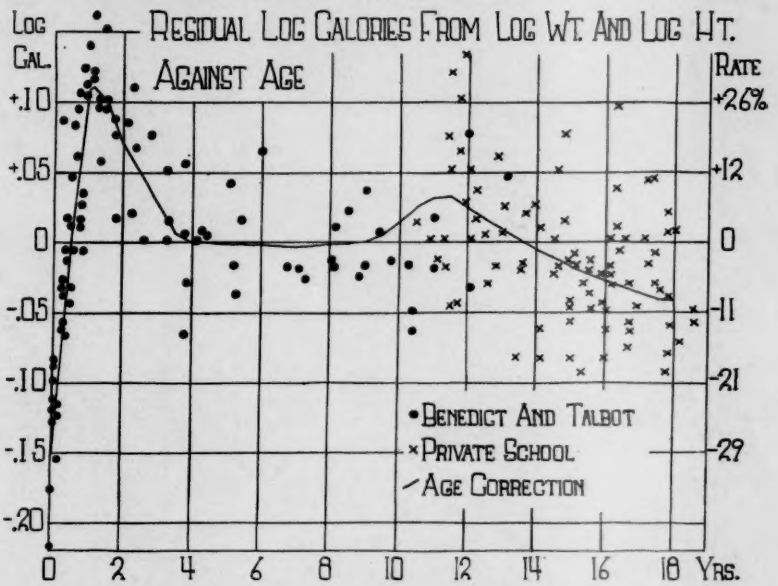

Fig. 3.—Scatter diagram of residual (logarithmic) calories from the linear regression (3) of the logarithm of calories on the logarithm of the weight and the logarithm of the height for the basic series against age showing the graphic correction for age.

which was a trifle lower than that of the formula (1), involving $\sqrt{W/H}$. Thus, the standard deviation of the variations remaining after removal of the effect of weight and height by (3) and the effect of age by graphic means from the 179 measurements of basal metabolism of normal [11] girls of ages from birth to 18 years, inclusive, is that per-

11. The girls were normal from a clinical point of view in every way and were not more than 20 per cent above or more than 10 per cent below the Baldwin-Wood standard for weight in terms of height (age being neglected). It may be noted that about one third of the measurments departed from the calculated values by more than 10 per cent and about one twentieth by more than 20 per cent—in accord with the usual statistical findings on distributions.

centage (10 per cent) which traditionally separates a normal from an abnormal subject (fig. 4).

3. GRADUATION OF THE SERIES

The relations between $c = \log C$, $w = \log W$ and $h = \log H$ are not strictly linear. An effort to fit log C to a cubic expression in log W showed systematic variations of observations from the fit too large to be tolerated. It seemed best, therefore, to graduate log C against log W by an arithmetical rather than an algebraic procedure (fig. 5). For this purpose the method of Whittaker [12] was used, dividing log W into 14 equal intervals, obtaining the means of the logarithms of the value of C which fall in the intervals, centering these at the middle of the intervals

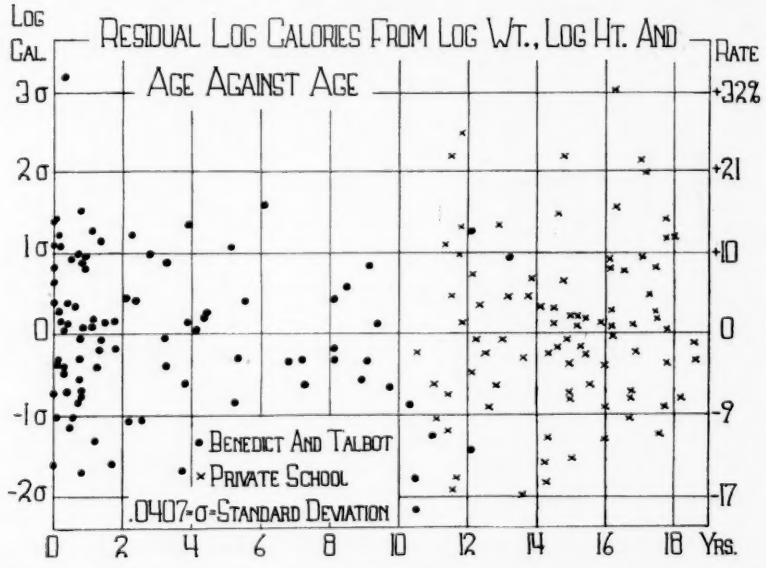

Fig. 4.—Scatter diagram of residual (logarithmic) calories from the linear regression (3) when the graphic correction for age has been applied.

(by interpolation, using the means of log W) and graduating the points thus obtained (with equal weights despite the varying numbers of observations going into the means) with various different values of the disposable parameter ϵ. Finally, the value of ϵ was chosen (viz, $\epsilon = 0.01$) which seemed to give the best compromise between fidelity and smoothing when account was taken of the goodness of fit to be obtained in view of the standard deviations to be expected in the means by virtue of the scatter of the observations and the number of observations

12. Whittaker, E. T., and Robinson, G.: Calculus of Observations, New York, D. Van Nostrand Co., 1924, p. 303.

entering into the means.[13] A similar graduation of log C against log H was made (in this case with $\epsilon = 0.05$ instead of $\epsilon = 0.01$, as giving the best compromise between fidelity and smoothing).

The graduated values were then interpolated to second differences (applied to the logarithms), and the interpolated values were entered in tables reading directly from weight expressed in kilograms or height expressed in centimeters to calories per twenty-four hours (tables 3 and 4). These tables represent the basic norms that we use throughout the rest of the discussion. With the 179 measurements as a basis, we cannot give better tables for the heat production to be expected, on the

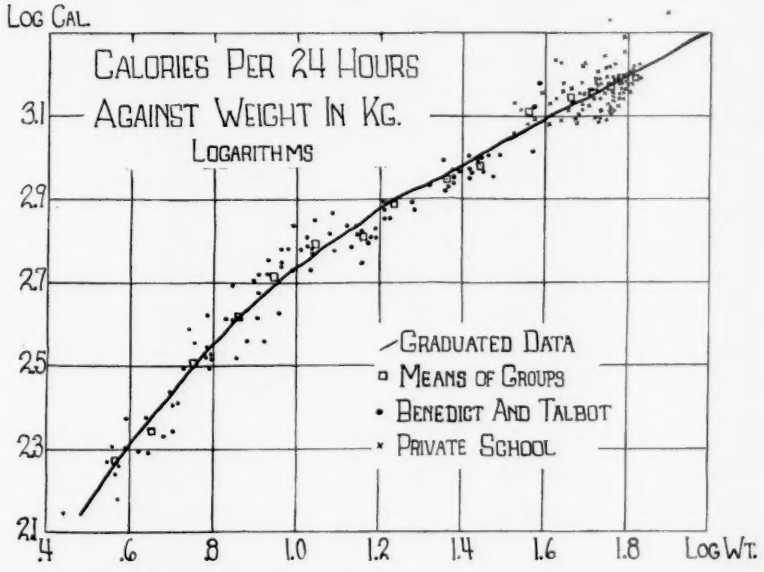

Fig. 5.—Scatter diagram of (logarithmic) calories per twenty-four hours against logarithm of the weight showing the curvilinear regression line obtained by graduation and the relatively uniform scatter about this line for different weights.

13. The object of "smoothing" is to remove the accidental variations, while that of "fidelity" is to adhere to the observations. If the data were sufficiently numerous and truly representative, the means of the different groups would be so well established that it would merely be necessary to interpolate between them, using successive differences. When the means are based on relatively few observations they are subject to "sampling errors," which should be removed by the smoothing process to the extent that the departures of the observed means from the smooth curve would give a value of X^2 (the test for the goodness of fit), indicative of a probability in the neighborhood of $P = 0.50$. To smooth more than this is to lose some of the significance of the observations; to smooth less than this is to incorporate some of the sampling errors into the graduation.

average, from the weight or the height individually. In the tables are also entered the graduations of height against weight and of weight against height obtained by similar methods.

TABLE 3 *A.—Graduated Values of Standard Total Calories and Heights Based on Weight*

Weight		Height		Calories per 24 Hours	Weight		Height		Calories per 24 Hours
Kg.	Lb.	Cm.	In.		Kg.	Lb.	Cm.	In.	
3	6.6	48.5	19.1	136	34	75.0	141.3	55.6	1,137
4	8.8	52.9	20.8	205	36	79.4	144.4	56.9	1,173
5	11.0	57.2	22.5	274	38	83.8	147.1	57.9	1,207
6	13.2	61.6	24.3	336	40	88.2	149.7	58.9	1,241
7	15.4	65.9	25.9	395	42	92.6	152.1	59.9	1,274
8	17.6	70.1	27.6	448	44	97.0	154.4	60.8	1,306
9	19.8	74.2	29.2	496	46	101.4	156.5	61.6	1,338
10	22.0	78.2	30.8	541	48	105.8	158.4	62.4	1,369
11	24.3	82.1	32.3	582	50	110.2	160.2	63.1	1,399
12	26.5	85.9	33.8	620	52	114.6	161.9	63.7	1,429
13	28.7	89.6	35.3	655	54	119.0	163.4	64.3	1,458
14	30.9	93.2	36.7	687	56	123.5	164.9	64.9	1,487
15	33.1	96.6	38.0	718	58	127.9	166.2	65.4	1,516
16	35.3	99.8	39.3	747	60	132.3	167.5	65.9	1,544
17	37.5	103.0	40.6	775	62	136.7	168.6	66.4	1,572
18	39.7	106.1	41.8	802	64	141.1	169.7	66.8	1,599
19	41.9	109.0	42.9	827	66	145.5	170.7	67.2	1,626
20	44.1	111.8	44.0	852	68	149.9	171.6	67.6	1,653
22	48.5	117.1	46.1	898	70	154.3	172.5	67.9	1,679
24	52.9	122.0	48.0	942	72	158.7	173.3	68.2	1,705
26	57.3	126.5	49.8	984	74	163.1	174.0	68.5	1,731
28	61.7	130.7	51.5	1,025	76	167.6	174.8	68.8	1,756
30	66.1	134.5	53.0	1,063	78	172.0	175.4	69.1	1,781
32	70.5	138.1	54.4	1,101	80	176.4	176.0	69.3	1,805

TABLE 3 *B.—Age Correction to Standard Total Calories Based on Weight*

Age			Age			Age		
Yr.	Mo.	Percentage*	Yr.	Mo.	Percentage*	Yr.	Mo.	Percentage*
0	0	— 3.1	5	0	—7.1	12	0	+8.6
0	3	— 3.0	5	6	—6.9	12	6	+7.6
0	6	— 2.4	6	0	—6.7	13	0	+5.4
0	9	+ 5.2	6	6	—6.7	13	6	+3.5
1	0	+12.7	7	0	—6.5	14	0	+1.4
1	3	+13.6	7	6	—6.1	14	6	0
1	6	+12.7	8	0	—5.6	15	0	—1.4
1	9	+ 7.4	8	6	—4.9	15	6	—2.1
2	0	+ 2.3	9	0	—4.3	16	0	—2.7
2	6	— 1.8	9	6	—3.2	16	6	—3.4
3	0	— 2.1	10	0	—1.6	17	0	—4.1
3	6	— 5.6	10	6	0	17	6	—4.5
4	0	— 6.5	11	0	+4.7	18	0	—4.9
4	6	— 6.9	11	6	+8.4			

* The percentage by which calories read from the weight table 3A should be increased or decreased.

4. GRAPHIC CORRECTION FOR AGE

Next the deviations of the individual measurements from the norms were plotted against weight, height and age. The deviations against weight and height were, of course, not affected by systematic errors; but the deviations when plotted against age showed systematic varia-

tions (fig. 6). Figures 3 and 6 are plotted to the same scale and exhibit the free hand graphic corrections for age for the linear regression on weight and height, formula (3), and for the curvilinear graduation against weight alone (table 3). The standard deviation of the variations from the figures obtained by the graduation against weight (uncorrected for the systematic age effects) is 0.0494 (logarithmically), or 12 per cent, less than the 16 per cent by (3). With the graphic correction for age the variation is 0.0435 (logarithmically), or 11 per cent, showing little reduction.[14] The standard deviation of the variations from the

TABLE 4.—*Graduated Values of Standard Total Calories and Weights Based on Height*

Height		Weight		Calories per 24 Hours	Height		Weight		Calories per 24 Hours
Cm.	In.	Kg.	Lb.		Cm.	In.	Kg.	Lb.	
48	18.9	2.9	6.4	134	116	45.7	21.5	47.4	854
50	19.7	3.3	7.3	159	118	46.5	22.3	49.2	873
52	20.5	3.7	8.2	186	120	47.2	23.1	50.9	894
54	21.3	4.2	9.2	214	122	48.0	24.0	52.9	913
56	22.0	4.6	10.1	246	124	48.8	24.9	54.9	932
58	22.8	5.1	11.2	278	126	49.6	25.8	56.9	951
60	23.6	5.6	12.3	309	128	50.4	26.8	59.1	969
62	24.4	6.1	13.4	341	130	51.2	27.8	61.3	987
64	25.2	6.6	14.6	373	132	52.0	28.9	63.7	1,011
66	26.0	7.1	15.7	404	134	52.8	30.0	66.1	1,042
68	26.8	7.6	16.8	433	136	53.5	31.1	68.6	1,072
70	27.6	8.1	17.9	462	138	54.3	32.4	71.4	1,101
72	28.3	8.6	19.0	489	140	55.1	33.6	74.1	1,130
74	29.1	9.1	20.1	515	142	55.9	34.9	76.9	1,160
76	29.9	9.6	21.2	539	144	56.7	36.3	80.0	1,192
78	30.7	10.1	22.3	560	146	57.5	37.7	83.1	1,225
80	31.5	10.6	23.4	581	148	58.3	39.2	86.4	1,259
82	32.3	11.1	24.5	601	150	59.1	40.8	89.9	1,294
84	33.1	11.6	25.6	619	152	59.8	42.3	93.3	1,329
86	33.9	12.2	26.9	636	154	60.6	44.0	97.0	1,365
88	34.6	12.7	28.0	652	156	61.4	45.8	101.0	1,408
90	35.4	13.2	29.1	666	158	62.2	47.6	104.9	1,447
92	36.2	13.7	30.2	681	160	63.0	49.5	109.1	1,477
94	37.0	14.3	31.5	695	162	63.8	51.5	113.5	1,504
96	37.8	14.9	32.8	709	164	64.6	53.5	117.9	1,531
98	38.6	15.4	34.0	722	166	65.4	55.6	122.6	1,552
100	39.4	16.0	35.3	735	168	66.1	58.0	127.9	1.568
102	40.2	16.6	36.6	748	170	66.9	60.1	132.5	1,584
104	40.9	17.2	37.9	762	172	67.7	62.5	137.8	1,594
106	41.7	17.9	39.5	777	174	68.5	65.0	143.3	1,595
108	42.5	18.6	41.0	792	176	69.3	67.6	149.0	1,596
110	43.3	19.2	42.3	807	178	70.1	70.2	154.8	1,598
112	44.1	19.9	43.9	822	180	70.9	73.2	161.4	1,600
114	44.9	20.7	45.6	838					

14. It may be noted that the weight graduation (table 3) corrected graphically for age (0.0435) does not give quite so good a fit to these data as the linear regression (3) on the weight and height, also corrected graphically for age (0.0407), despite the fact that the uncorrected weight graduation (0.0494) gives a considerably better fit (0.0640) than the uncorrected regression (3). What this means is that the age corrections for the deviations from (3) are larger and more regular than those for the deviations from the standards shown in table 3. So much for this group. We have found, however, that for other groups which we have examined the standard deviations (from the means of the respective groups) from the standards shown in table 3 (uncorrected for age) are on the whole about the same as those from (3) corrected for age—being 0.0368 and 0.0358, respectively—and both are less than for our group, i. e., the other groups seem to be less variable internally.

figures obtained by the graduation against height (uncorrected for age) is 0.0495, or again 12 per cent, so that for this particular group of 179 measurements the prediction of the heat production on the basis of either weight or height alone is equally good. With the graphic correction for age the figure is 0.0441, or 11 per cent.

5. CORRELATION BETWEEN DEVIATIONS FROM DIFFERENT STANDARDS

If the deviations as obtained from the weight graduation are plotted against those obtained from the height graduation, the figure (fig. 7) shows a high correlation, $r = 0.85$; i. e., the girls who had a high (or low) metabolic rate as computed from their weight had ordinarily a

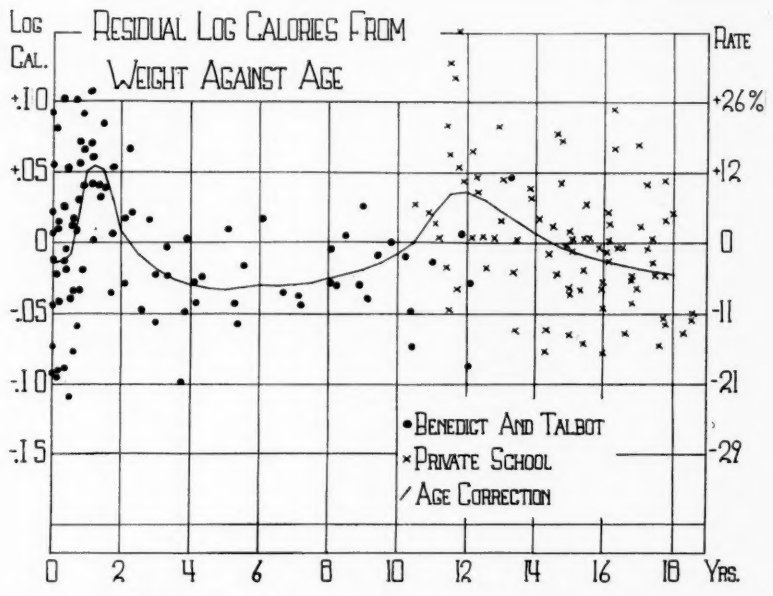

Fig. 6.—Scatter diagram of residual (logarithmic) calories from (logarithmic) weight as obtained from the curvilinear graduation plotted against age to show that there remains a graphic correction for age to be applied.

high (or low) metabolic rate on the basis of their height. For the variations based on the weight and height each as corrected (graphically) for the age, $r = 0.87$ in place of 0.85.

If one restricts the considerations to the 58 measurements for girls above 14 years, for whom an estimate of heat production may be had on the Aub-Du Bois standard, one finds correlations of residuals from that standard of $r = 0.85$ with those from our weight table and of $r = 0.83$ with those from our height table. Moreover, the correlation of the variations of the calories from the values predicted from height

and from weight individually is r = 0.93 (instead of the value r = 0.85 for the total group of 179). Finally, if the variations of the calories from height or from weight are correlated individually with the variations from our height-weight-age estimates (formula 1) as graphically corrected for age, the values remain in the neighborhood of r = 0.93.

For the older group of 58, the standard deviation of the variations from the weight table is only 5.1 per cent, instead of the 12 per cent found for the whole group of 179 (which is only about the magnitude of the standard error of single measurements of C), whereas that for the variations from the height table is 9 per cent (instead of 12 per cent), that for the variations from the Aub-Du Bois table is 6.5 per cent and

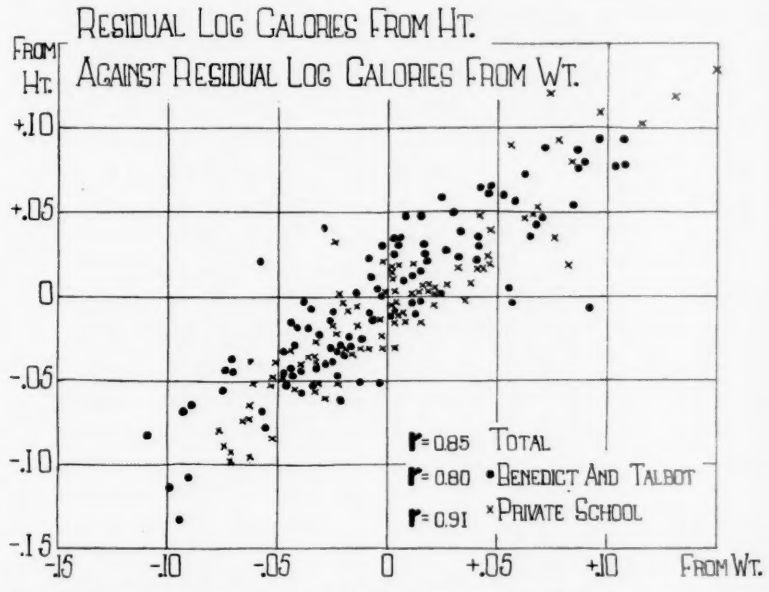

Fig. 7.—Scatter diagram of residual (logarithmic) calories when computed from separate graduations against (logarithmic) weight and (logarithmic) height, showing the high correlation between the two sets of residuals and the relatively perfect intermingling of the points representing the two series into the basic series.

that for the variations from the linear weight-height regression (3) corrected graphically for age is 6.9 per cent. This shows close fitting for this group.

As our basic graduations of calories against weight and against height furnish standards which when applied to individual girls give different estimated basal metabolic rates to compare with the observed values, one might infer that a combination of those two standards would furnish an even better estimate. This is of course true, and the procedure would correspond in a general way to basing the estimate on

both height and weight, as is done by such a formula as (3), though in a different way. The amount of the improvement will be small because of the high correlation between the residuals ($r = 0.85$ or so). If one has observed values c, the two estimates c_w and c_h, based on weight and height separately, and the residuals $u = c - c_w$ and $v = c - c_h$ (which vanish in the mean), the combined standard $fc_w + (1 - f)c_h$ will have residuals $z = fu + (1 - f)v$, also vanishing in the mean. If then r_{uv} is the correlation between u and v, it may be shown that

$$\sigma_z^2 = \frac{\sigma_u^2 \sigma_v^2 (1 - r_{uv}^2)}{\sigma_u^2 + \sigma_v^2 - 2r_{uv}\sigma_u\sigma_v}$$

for that determination of the combining weights f and $1 - f$ which gives the best fit (i. e., makes σ_z^2 least). For the whole group of 179 the values are $\sigma_u = 0.0494$, $\sigma_v = 0.0495$, $r = 0.85$ and $\sigma_z = 0.0475$, indicating a percentage variation of 11.5 instead of 12. Such a small improvement for the group as a whole is probably not so valuable in considering the individual case as is the light thrown by the two different estimates, in the few cases in which they are significantly different.

6. CORRECTIONS FOR HEIGHT AND WEIGHT

The question naturally arose as to how far the estimates of calories from weight (table 3) might be altered by allowing for height. A graduation by the Whittaker method was made for height against weight for the 179 basic measurements. Then one could get residual calories (logarithmic) from the weight standard and residual height (logarithmic) from the curvilinear graduation for height against weight (table 3) and obtain the correlation between the two residuals, a sort of partial correlation, for which the value, $r = 0.079$, showed practically no effect of height. The regression equation of residual calories against residual height had a slope of 0.3. As the standard deviation of residual heights was only 0.0111, the correction to the calories for residual height would be for two thirds of the subjects between $\pm$ 0.0033, and as all the figures are in logarithms the correction in the calories would be less than 1 per cent. Practically speaking, there is, within the normal range for weight to height, no height correction to the value of calories as determined from weight alone.

If one undertakes to interchange the rôles of weight and height (which requires a curvilinear graduation of weight against height), one finds as the correlation of residual calories from the height table with residual weights from the graduation of weights against height $r = 0.184$. The regression equation of residual calories against residual weight has, again, a slope of approximately 0.3, but since the standard deviation of residual weights is 0.0306, the correction to the calories for this residual weight is 0.0085, or 2 per cent. Although this is two

and one-half times the correction found when weight was made basic, it is negligible in view of the error of a single measurement of basal metabolism.[15]

7. CORRECTIONS FOR RATE OF GROWTH AND FOR PULSE RATE

For 57 of the 179 children (all 57 from the private school group) measurements of weight and height were available at times before and after the determination of the basal metabolism, so that estimates of the rate of growth per annum were possible (see sections 21 and 24). When the percentage increase in weight for the year and the residual calories from the weight table are correlated, the coefficient is $r = 0.26 \pm 0.13$, the standard deviation of the rate of growth is 7 per cent and the correction to the calories is by a regression equation with a slope or trend of 0.0019. For the standard deviation of 7 per cent this means a correction to the calories of 3.1 per cent, or four times the correction for excess height. If we may generalize from this subsample of 57, the percentage rate of annual growth in weight is four times as effective in increasing the heat production estimated from the weight as is the variation in height from the standard for the given weight.

When height was taken as the basic variable, the correlation of residual calories from height with the percentage rate of growth in height was $r = 0.52$, the standard deviation of percentage growth in height was 2.79 and the increase in calories for this standard percentage rate of annual growth was 6 per cent, about twice the magnitude of the weight correction previously found. One may take other partial correlations; for example, if one corrects the residual calories as estimated from weight by applying the graphic correction for age and

15. We ordinarily take weight as basic to the estimation of calories and height as basic to weight; indeed, our definition of normal is that the weight lies between −10 per cent and +20 per cent of the Baldwin-Wood standard of weight for given height, age being neglected. This being so, one might ask what correction is to be applied to calories estimated from weight for the departure of weight from the standard for height. If our weight for height standard is used in place of the Baldwin-Wood standard, the correlation of excess calories (Δc) within the "normal" range as estimated from weight with excess weight (Δw) as estimated from height (all figures being in logarithms and hence equivalent to percentages) is $r = -0.137$ and the regression equation is $\Delta c = -0.22\,\Delta w$. The standard deviation of Δw is 0.031, and hence two thirds of the subjects have an excess weight correction to the estimated calories lying between ± 0.0068, which is only ± 1.6 per cent and well within the error of measure of C. Of course, in the case of girls much over or much under the standard weight for height, the correction might be more important, but then one should not apply the regression equation here found, if only because the value of the trend coefficient (-0.22) is poorly determined statistically; we shall return to this matter later in discussing overweight and underweight girls (see section 27).

then correlates with the rate of growth in weight, the result is only $r = 0.05$, which is much less than the standard deviation of sampling (0.13).

For 83 of the measurements (for the private school group) the correlation between residual calories from weight and the pulse rate was $r = 0.39$. The standard deviation of the pulse rate was 7.9 beats per minute, and for this deviation the excess of calories was 4.3 per cent, intermediate between the effects for rate of growth in weight and rate of growth in height. The increase of calories per pulse beat per minute for this group was 0.52 per cent, and as the mean number of calories was in the neighborhood of 1,500, this corresponds to an increase of about 8 calories per pulse beat per minute. As both pulse rate and growth rate are accompanied by an increase in heat production of a comparable amount, the question arises as to whether pulse rate and growth are correlated. For only 57 of the subjects are both measurements available, but for these 57 there is correlation ($r = 0.25$) between the two variables—the effects are not strictly independent.[16]

8. PUBERTAL RISE IN BASAL METABOLISM

The 92 children of the Benedict and Talbot series were in the prepubertal age range; the 87 children of the Talbot private school series were in an age range that included the age of puberty, but as the age of puberty for each of the girls was unknown, the question of a pubertal rise in heat production cannot be discussed in connection with that series (see section 23). The results of Topper and Mulier[17] indicated a prepubertal rise of about 100 calories followed by a postpubertal drop of about the same amount, but there was also a prepubertal rise of the pulse rate and a subsequent drop of about 13 beats per minute, which, at the rate of 8 calories per beat, would account well enough for the rise. Unpublished and incomplete data by Marian E. Stark (Madison, Wis.), to which we have had access, do not indicate any such rise and fall either in heat production or in pulse rate.

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16. In connection with heat production in relation to pulse rate there are two procedures, leading to different descriptions of different phenomena: (1) The variations of the pulse rate of the individual girls of a group from the mean of the group may be correlated with the residual calories of the girls as estimated from the weight (or any other) table—it is this correlation we used. (2) The variations of the pulse rate of the individual girl from her individual mean may be correlated with the variation in her heat production. The first may be called an intergirl correlation and the second an intragirl correlation. The results of Blunt and Dye (Blunt, K., and Dye, M.: J. Biol. Chem. **47**:69, 1921) give a positive value of $r = 0.14 \pm 0.26$ for the intergirl correlation, compared with ours of $r = 0.33 \pm 0.11$; the values of the intragirl correlations for their series vary from $+0.87$ to -0.77, about a median of 0.13, or a weighted mean of 0.24 ± 0.07.

17. Topper, A., and Mulier, H.: Basal Metabolism of Normal Children: The Puberty Reaction, Am. J. Dis. Child. **43**:327 (Feb.) 1932.

9. ERRORS OF OBSERVATIONS ON BASAL METABOLISM

In a critical discussion of the basal metabolism in terms of other variables, for comparison with the measured values, we proceed by the method of examining the mean squares of the deviations of the observed values from the calculated ones (see section 25, part 4). If the values of c are referred to their mean $\bar{c}$, the mean value σ_c^2 of $(c - \bar{c})^2$ gives the variance from the mean. Here no other measure than that of c is involved. A certain variation is inherent in the measurement of any physical quantity; if the variation observed is no more than that inherent in the measurement itself, there is no use trying to relate the variable to any other variables for the purpose of accounting for some of the variation—one merely seeks to improve the technic of the measurement. It is therefore of the first importance in approaching the discussion to determine so far as possible the error of measurement of basal metabolism. Presumably the error of measurement differs for different methods of measurement, such as the cot chamber or the portable apparatus method, and there may be systematic differences between such methods; it is also possible that different observers using the same method will have different errors of measurement. To discuss such errors one should have repeated determinations on the same persons, and even then the variation between the different determinations may be due in part to instrumental variations and in part to unobserved variations in the basal metabolism itself—because a person can hardly be expected to be in exactly the same state with reference to basal metabolism on different occasions any more than an instrumental procedure can be expected to give precisely the same results even if the subject is in identically the same state. For our purposes one need not keep the distinction between instrumental and personal variations; both may be thrown together into the error or variation of the determination of basal metabolism.

Benedict [18] in 1932, taking himself as subject, made an extensive series of tests, with a mean oxygen consumption of 231.6 cc. per minute and a standard deviation of 5.42 for 18 observations; this is a percentage variation of 2.34, which on a logarithmic basis should be 0.0101, or $\sigma^2 = 0.00010$. In 1933 he made a series of 33 observations, with a mean of 229.3 and a standard deviation of 4.56, making a percentage variation of 2 when 4 high observations were rejected because of emotional excitement; the difference between the means 231.6 and 229.3 is not significant. When, however, the results of the 4 rejected observations are included, the mean is 231.9 and the standard deviation is 7.4, making a percentage variation of 3.2. The author concluded that the basal metabolism is highly constant. It is doubtful, however, that one

18. Benedict, F. G.: Am. J. Physiol. **110**:521, 1935.

can fairly apply the small variation, of from 2 to 3 per cent, which he finds for measurements on himself to measurements on a variety of young girls who are unaccustomed to having their basal metabolism determined, who may be under an average continued excitement in excess of that of the experienced subject and who, furthermore, are presumably not so well under control in other respects. An interesting experiment is the attempt of a trained subject to increase his "basal" metabolism voluntarily as much as possible without being detected therein by trained observers.[19] The mean of 17 normal observations was 214, with $\sigma = 5.56$, or a variation of 2.6 per cent. These results are similar to those of Benedict. With the effort to increase the metabolism unobserved the mean figure was 255, an increase of 41, or 19 per cent! Thus it appears that something like a 9 or 10 per cent variation from a midvalue may be voluntarily induced without detection. It is conceivable that an untrained subject of the age we are discussing might have a similar variation involuntarily without the observer's detecting any absence of conditions appropriate to a determination of basal metabolism.

The extensive investigation of Blunt and Dye [20] on 16 women, aged from 21 to 44, in which from 5 to 25 determinations were made on each subject, showed an average standard deviation from the mean for each subject of 0.0159, on a logarithmic base, corresponding to a percentage variation of 3.7. (In these observations duplicate tests were required to agree within 5 per cent.) Remington and Culp [21] made three sets of observations on 41 student nurses. The three means were (in chronological order, in logarithms) 3.1271, 3.1227 and 3.1202. These show a decrease, as is not unfamiliar with successive observations. The standard deviations (logarithmic) were, respectively, 0.0432, 0.0535 and 0.0457. Taking a standard deviation of 0.0475, the standard deviation of the standard deviation should be 0.0052; so the observed variations in the standard deviations are of about the expected magnitude. The standard deviation of the mean is 0.0074, and the means clearly vary less than this. Turning from the values for the group as a whole to the differences between the three observed values for the individual members of the group, one finds for the standard deviation of those differences an average of 0.03125, or 7.4 per cent. The standard deviation of such a difference is, however, $\sqrt{2}$ times as large as that of the

19. Carpenter, T. M.; Hoskins, R. G., and Hitchcock, F. A.: Am. J. Physiol. **110**:320, 1934.

20. Blunt, K., and Dye, M.: J. Biol. Chem. **47**:69, 1921.

21. Remington, R. E., and Culp, F. B.: Basal Metabolic Rate of Medical Students and Nurses in Training at Charleston, S. C., Arch. Int. Med. **47**:366 (March) 1931.

variation from the mean, and thus 5.2 per cent is an estimate of the standard deviation of the values for the basal metabolism for this group of 41 persons. Finally, there are the repeated measurements on a group of 64 persons by Marian Stark.[22] The standard deviation of the differences of the values for the same subjects was 5.7 per cent, indicating an "error of determination" of 4 per cent.

Summing up this discussion, we infer that the error of determination in the sense in which we have defined it may well be set at around 5 per cent. This corresponds to a standard deviation (logarithmic) of $\sigma = 0.0212$ and a variance (logarithmic) of $\sigma^2 = 0.00045$. If this is a sound estimate for any particular series of observations in which the basal metabolism is to be related to other variables, one cannot expect to reduce the variance of the measurements (by fitting linear or other expressions in those variables) to less than 0.00045. It may be noted that for the group of 58 older girls in the private school series (see section 5) it was found that the standard deviation of the variations from our weight table was only 5.1 per cent. If this is not fortuitously an unusually good fit, and if the error of determination was 5 per cent, the variation for this group is as completely explained as can be expected, and the introduction of other variables should give no improvement.

10. REGRESSION EQUATIONS FOR DIFFERENT SETS OF VARIABLES

We examined the effects of weight, height and age on heat production by the method of graduation and even extended the considerations to a sort of partial correlation through graduating weight and height against each other, but the age correction was applied after computing residuals from weight or height and so were the corrections for the three other variables, pulse, percentage rate of growth in height and percentage rate of growth in weight. When a number of variables are correlated with one another and with the dependent variable, successive corrections do not give an adequate picture of the amount of variation in the dependent variable which can be accounted for by the independent variables. However, as all seven variables, C, W, H, A, P, R_h and R_w, are known for only 57 of our subjects, it would be impracticable to graduate each variable with respect to all the others, and as the 57 subjects were in a relatively limited range of age, it seems feasible to apply the method of partial correlation. Of course, with so few as 57 subjects the coefficients of correlation have large sampling errors and any regression equations will have coefficients which are poorly determined; nevertheless, it seemed worth while to find out what the relative effects of these variables are for this sample.

22. Stark, M. E.: Tr. Wisconsin Acad. Sc. **27**:251, 1932.

The correlation coefficients of zero order between the variables are given in table 5. The method of estimating the amount of the variation in c which is under control when the effect of one or more of the independent variables is taken into account is to give the value of σ_v^2, the average of the square of the residual, v, when using a regression equation involving that variable or those variables. The value of σ_c^2 for c relative to the mean is $\sigma_c^2 = 0.002892$. One may begin by giving for this group of 57 the value of σ_v^2 from our previous graduations:

$\sigma_v^2 = 0.002398$	curvilinear graduation from weight
$\sigma_v^2 = 0.002460$	curvilinear graduation from height
$\sigma_v^2 = 0.002113$	curvilinear graduation from weight and age

These values were obtained from graduations fitted over the whole group of 179 data for the entire age range. If one fits linear regression

TABLE 5.—*Correlation Coefficients of Zero Order Between c, w, h, A, P, R_h, R_w for 57 Girls*

	w	h	*A*	*P*	R_h	R_w
c	0.4978	0.4880	0.2763	0.3908	0.1892	—0.1138
w	.....	0.9207	0.7489	0.0260	—0.4028	—0.4743
h	.....	.....	0.7418	—0.0327	—0.3742	—0.5143
A	.....	.....	.....	—0.0955	—0.6649	—0.5941
P	.....	.....	.....	.....	0.2480	—0.0462
R_h	.....	.....	.....	.....	.....	0.4896

equations to this particular group of 57, one has corresponding values of σ_v^2, namely.

$\sigma_v^2 = 0.002175$	allowing for weight alone
$\sigma_v^2 = 0.002203$	allowing for height alone
$\sigma_v^2 = 0.002114$	allowing for weight and age

It may be observed that the rectilinear regressions calculated for the group of 57 give better results than the graduations based on the whole series of 179 for weight and for height and the same result for weight and for age.

The total variance, $\sigma_c^2 = 0.002892$, has been reduced to about three quarters of its value by these allowances; that is, weight, height or weight and age do not account for more than about a quarter of the variance as measured by σ^2. The values of σ_v^2 when the six variables are individually allowed for are 0.002175 (w), 0.002203 (h), 0.002671 (*A*), 0.002415 (*P*), 0.002788 (R_h) and 0.002854 (R_w). Thus it appears that age or rate of growth whether in height or in weight when taken individually is not so effective as the pulse rate in reducing σ^2 and that this is decidedly less effective than weight or height.

If two independent variables are chosen, the values of σ_v^2 are as in table 6. From this table it may be seen that, at least for this sample of girls, the two variables which are most effective are weight and percentage growth in height, which taken together reduce σ^2 almost as much from the value for weight or height alone as that is reduced from the original value, whereas weight and height together give little reduction beyond the values for each alone.

We did not tabulate the values of σ_v^2 for all possible combinations of three variables but noted first that if w, h and A were taken out, the result was $\sigma_v^2 = 0.002081$, which is not much less than for w and h individually and nowhere nearly so small as for the pair of variables w and R_h or even w and P or h and P. This shows that it is entirely reasonable to expect that other variables than height, weight and age must be introduced into the picture if one is to get important reductions in σ_v^2 toward some such value as 0.0005, which may be presumed

TABLE 6.—*Values of Residual Variance, σ_v^2, for Pairs of Variables*

	h	A	P	R_h	R_w
w	0.002159	0.002114	0.001762	0.001651	0.002119
h	.....	0.002156	0.001724	0.001738	0.002129
A	.....	.....	0.002163	0.001950	0.002659
P	.....	.....	.....	0.002424	0.002424
R_h	.....	.....	.....	.....	0.002626

to represent errors of determination of c. In the second place, there are two sets of three variables, namely, pulse and rate of growth in height, which taken with either weight or height reduce σ_v^2 considerably below the best value for two variables (w and R_h), viz, $\sigma_v^2 = 0.001442$ (w, P and R_h) and $\sigma_v^2 = 0.001451$ (h, P and R_h). These figures show that the original value of σ^2 (0.002892) has been cut in half by the use of either of these sets of three variables.

Finally, one may take out all six of the variables. The regression equation is, in standard measure:[23]

$$\frac{c}{\sigma_c} = 0.2633\,\frac{w}{\sigma_w} + 0.2903\,\frac{h}{\sigma_h} + 0.2503\,\frac{A}{\sigma_A} + 0.3134\,\frac{P}{\sigma_P} + 0.4396\,\frac{R_h}{\sigma_{R_h}} + 0.1084\,\frac{R_w}{\sigma_{R_w}} \qquad (4)$$

23. In the regression equation (4), the symbols c, w, h, A, P, R_h and R_w represent not the absolute values themselves but the differences between those values and their means in the group; if one wishes to use for this group the absolute values one must add to the equation the constant k, which is

$$k = \frac{\overline{c}}{\sigma_c} - 0.2633\,\frac{\overline{w}}{\sigma_w} - 0.2903\,\frac{\overline{h}}{\sigma_h} - 0.2503\,\frac{\overline{A}}{\sigma_A} - 0.3134\,\frac{\overline{P}}{\sigma_P} - 0.4396\,\frac{\overline{R}_h}{\sigma_{R_h}} - 0.1084\,\frac{\overline{R}_w}{\sigma_{R_w}}$$

(Footnote continued on next page)

with $\sigma_v^2 = 0.001351$. In other words, while the total variance, $\sigma^2 = 0.00289$, is reduced to $\sigma_v^2 = 0.00218$ when one allows for w, and further to $\sigma_v^2 = 0.00165$ when one allows for w and R_h, and still further to $\sigma_v^2 = 0.00144$ when one allows for w, P and R_h, it is reduced only to $\sigma_v^2 = 0.00135$ when allowance is made for all six variables. Furthermore, it must be pointed out that the values given for σ_v^2 are the actual means of the squares of the deviations in this sample and not the values which would be predicted for the universe from which the sample is drawn, which would be larger in the ratios 57/55, 57/54, 57/53 and 57/50 according as allowance was made for one, two, three or six variables. Thus, to compare the value 0.00144 for three variables with the value 0.00135 for six variables, one would have to multiply the latter by 53/50, which would increase it by 6 per cent, to 0.00143, representing practically no reduction. This means, if one can judge by this sample, that one must look for other variables than h or A or R_w if one would improve the estimation of heat production over that found for w, P and R_h.

If additional variables could be found and measured and if they were correlated with the important variables already introduced, the coefficients in the regression equation affecting the variables now in it might be much altered.[24] For the equation as it stands one may say that relative to their variability within the sample of 57 and without regard to their intercorrelations, the contributions of w, h, A and P are more or less equal, whereas the contribution of R_h is larger and that of R_w much smaller.

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where the bars over the letters represent the means of the respective variables for the group. To avoid multiplication of notation we shall hereafter use the symbols c, w, h and A to stand either for the values of log C, log W, log H and A or for these values diminished by their means in the group with which we are working; ordinarily it will be in the latter sense, since we shall rarely want to use the constant k and the absolute values in a regression equation because the groups prove to differ significantly with respect to their means and thus also with respect to k (see section 17). The equation is given in standard measure, i. e., with the values of the regression coefficients appropriate to the use of departures from the means estimated relative to their standard deviations in the group, so that the relative effectiveness of the different variables in view of their variabilities in the group may be at once apparent on comparing the magnitudes of the coefficients.

24. Recent work by N. B. Talbot (Basal Energy Metabolism and Creatinine in the Urine: I. Observations on Children, Am. J. Dis. Child. **52**:16 [July] 1936) on the relation of creatinine output to basal metabolism suggests one additional variable which may be used. Before one can discuss statistically its relation to the variables previously introduced, a long series of data involving all the measurements is necessary.

When rid of standard measure, the regression equation becomes [25]

$$c = 0.1852w + 0.6562h + 0.007591A + 0.002287P + 0.008477R_h + 0.0008356R_w \quad (5)$$

The equation must not be expected to hold for extrapolation to higher age ranges, because h, R_h and even w, R_w tend to become constant for the individual subject, while A advances steadily and whatever change there is in P is insufficient to counterbalance the increase in A; the equation therefore predicts increasing heat production with age, whereas the fact is that heat production decreases. Furthermore, one could not expect that the equation could safely be extrapolated backward.[26] The following seem to be the elements most needed for a better discussion of basal metabolism: (1) consistent records over long periods of growth or of life for the same persons, (2) larger series of measurements on different persons, including simultaneous measurements of a variety of variables and (3) the discernment of additional variables of importance and records of their values, along with those of the variables already believed to be of importance.

11. SEVERAL SERIES OF DATA FROM THE LITERATURE

Indications have been found that for the group of 57 private school girls, for whom data on the pulse and the rate of growth were available, the other variables had some significance in determining the basal metabolism. Considerable series of data are available in the literature or elsewhere in which the pulse rate is given in addition to the weight, height and age, and there are, of course, plenty of measurements with the weight, height and age specified. We shall next discuss some of the results obtained by applying the method of partial correlation to some of these series of data. One may query the adequacy of the method

25. The regression equations for the best results with one, two or three variables are

$c = (0.3500 \pm 0.0815)w$

$c = (0.4818 \pm 0.0783)w + (0.008967) \pm 0.002146)R_h$

$c = (0.4503 \pm 0.0746)\ w + (0.002045 \pm 0.000731)P + (0.007300 \pm 0.002111)R_h$

The standard errors of the regression coefficients are here indicated. In all these equations the variables are, of course, measured from their means.

26. There were, however, two 3 year old girls for whom all the variables except pulse were known, and for them the equation gives results that are in one case very good and in the other case not very good if the pulse, which is not particularly important in these cases, is taken as 90. That the correlation of c to A is negative for ages above 20 seems established; with regard to our positive correlation for the younger group it may be noted that such a result was found for the Benedict-Talbot series (ages from birth to 13 years) by Levine and Marples (Levine, S. Z., and Marples, Eleanor: The Respiratory Metabolism in Infancy and in Childhood: XII. A Biometric Study of Basal Metabolism in Normal Infants, Am. J. Dis. Child. **41**:1332 [June] 1932).

itself in view of the obvious curvilinearity of the relationships, which required us to work with graduations of the data, but for the most part the series about to be discussed have a narrow range of age during the growth period, and an examination of scatter diagrams shows no great indication of curvilinearity in the restricted age range and in view of the large amount of scatter in the basal metabolism; moreover, we do not see that any method better than that of partial correlation is available for the discussion of the material.

For synoptic reference the series is numbered with a specification as to observer, the normality of weight for height (from 10 per cent below to 20 per cent above by the Baldwin-Wood table), the number of girls in the series, the age range, the mean values of the variables (logarithms except for age and pulse) and the standard deviations of the distributions about the means (table 7).

12. CORRELATION COEFFICIENTS FOR THE DIFFERENT SERIES

The correlation coefficients between the variables are shown in table 8.

The variability of the correlation coefficients from group to group is obviously much larger than should be expected from the values of the standard deviations. In some cases there is a ready explanation of the large differences; for example, the correlation of w and A must be large and positive if the age range covers a considerable period of growth, but if the range is over ages which are subsequent to the practical completion of growth it is to be expected that the correlation will be small or even be negative. The correlation of the basal metabolism with the pulse rate exceeds twice its standard deviation for groups I (Talbot) and V (Coons) but is negative for group IX (Stark), yet the mean age for group I and for group IX are practically the same. (There are, however, a good many measurements on the same girls in group IX.) One might expect that if the standard deviations of the distribution were small the correlation coefficients, other things being equal, would be smaller. It would be possible to devote considerable comment to the variation in the coefficients, but such comment would probably be of meager significance.

13. REGRESSION EQUATIONS FOR THE DIFFERENT SERIES

As the aim is to estimate the basal metabolism from the values of the other variables, it is presumably of greater interest to examine the regression equations for the different groups in terms of the variables. It will be recalled that we took as fundamental in discussing Talbot's series a graduation of calories against weight alone; the graduation was based on 179 measurements over the age range from birth to 18 years. One need not expect this graduation to fit one of the restricted groups

TABLE 7.—*Description of Various Groups of Data, Giving Means and Standard Deviations of the Variables*

	Observer	Normality	No. of Girls	Age	c	σ_c	w	σ_w	h	σ_h	A	σ_A	P	σ_P
I	Talbot	Normal	57	10-16	3.1600	0.05377	1.7084	0.07646	2.2026	0.02379	13.89	1.774	74.75	7.368
II	Talbot	Normal	26	13-18	3.1669	0.05100	1.7619	0.04785	2.2195	0.01720	17.04	1.154	68.62	7.217
III	(I&II)	Normal	83	10-18	3.1621	0.05301	1.7251	0.07313	2.2079	0.02330	14.88	2.170	72.83	7.855
IV	Coons	Normal	98	16-35	3.0941	0.03376	1.7468	0.03856	2.2115	0.01301	21.44	3.674	69.97	7.625
V	Coons	Overweight	35	16-28	3.1560	0.06189	1.6834	0.07936	2.2100	0.02084	19.86	2.550	70.14	9.178
VI	Coons	Underweight	79	16-26	3.0643	0.03612	1.6738	0.03619	2.2120	0.01444	19.82	2.221	71.35	9.037
VII	Tilt	Normal	40	17-25	3.0890	0.03484	1.7192	0.04457	2.2032	0.01571	20.49	1.731	67.82	7.800
VIII	(IV&VII)	Normal	138	16-35	3.0926	0.03416	1.7399	0.04230	2.2091	0.01567	21.16	3.262	69.35	7.738
IX	Stark	Normal	52	9-16	3.1344	0.03608	1.6960	0.05698	2.1963	0.01951	13.16	1.778	74.25	10.54
X	Stark	Underweight	27	9-16	3.1093	0.03355	1.6119	0.06348	2.1956	0.01892	12.69	1.556	71.93	12.12
XI	McKay	Normal	80	13-18	3.1344	0.03755	1.7310	0.04782	2.2079	0.01514	16.44	1.221	.....	.....
XII	Lucas	Normal	218	8-18	3.0769	0.07295	1.5794	0.1311	2.1579	0.04371	11.13	2.265	.....	.....
XIII	Lucas	Underweight	107	8-18	3.0681	0.07850	1.5831	0.1173	2.1726	0.03826	11.36	2.533	.....	.....
XIV	Lucas	Overweight	34	8-16	3.1141	0.07250	1.6832	0.1190	2.1544	0.03926	10.94	2.412	.....	.....
XV	(XII-XIV)	Mixed	359	8-18	3.0778	0.07565	1.5754	0.1324	2.1620	0.04232	11.18	2.597	.....	.....

as well as it can be fitted even by a rectilinear regression of c on w as determined from the group itself. If, for example, group XII (Lucas' normal children) is considered, the mean value of c (in logarithms) is 3.0769. Now, if one uses the weight table and finds the residuals for

TABLE 8.—*Correlation Coefficients Between Pairs of Variables for the Fifteen Groups of Table 7*

	w	h	A	P	w	h	A	P
c	0.4978	0.4880	0.2763	0.3908	0.6796	0.5532	−0.2295	0.0740
w		0.9207	0.7489	0.0260		0.7289	0.0840	−0.0873
h			0.7418	−0.0327			−0.0593	−0.0448
A				−0.0955				−0.0625
	For I ($1/\sqrt{n} = 0.132$)*				For II ($1/\sqrt{n} = 0.196$)			
c	0.5172	0.4905	−0.0005	0.2642	0.3477	0.3947	−0.0839	0.0270
w		0.8991	0.6767	−0.1220		0.6835	0.1583	−0.3231
h			0.6438	−0.1528			0.0509	−0.2251
A				−0.3037				−0.1087
	For III ($1/\sqrt{n} = 0.110$)				For IV ($1/\sqrt{n} = 0.101$)			
c	0.7996	0.6578	−0.0807	0.4835	0.5802	0.4977	0.0829	0.1823
w		0.7887	0.0129	0.2695		0.7436	−0.0069	0.0005
h			−0.0807	0.1762			−0.1202	−0.0133
A				−0.0215				−0.1884
	For V ($1/\sqrt{n} = 0.169$)				For VI ($1/\sqrt{n} = 0.113$)			
c	0.5855	0.5541	−0.1045	0.2633	0.4207	0.4497	−0.0738	0.1057
w		0.7318	−0.2968	−0.1680		0.7189	0.1060	−0.2206
h			−0.1871	−0.2137			0.0418	−0.2084
A				−0.1396				−0.0907
	For VII ($1/\sqrt{n} = 0.158$)				For VIII ($1/\sqrt{n} = 0.085$)			
c	0.5117	0.5092	0.0535	−0.2711	0.6141	0.6657	0.5768	−0.1768
w		0.8013	0.4878	−0.4754		0.9567	0.7960	−0.4672
h			0.6967	−0.4971			0.8149	−0.4192
A				−0.3458				−0.2115
	For IX ($1/\sqrt{n} = 0.139$)				For X ($1/\sqrt{n} = 0.192$)			
c	0.5974	0.5052	−0.0608		0.6491	0.6494	0.5390	
w		0.6539	0.1494			0.9472	0.8266	
h			0.0629				0.8502	
	For XI ($1/\sqrt{n} = 0.112$)				For XII ($1/\sqrt{n} = 0.068$)			
c	0.6142	0.5897	0.4473		0.6737	0.6602	0.5110	
w		0.9421	0.8241			0.9396	0.8274	
h			0.8362				0.7823	
	For XIII ($1/\sqrt{n} = 0.097$)				For XIV ($1/\sqrt{n} = 0.171$)			
c	0.6488	0.5965	0.4935					
w		0.8483	0.7711					
h			0.8357					
	For XV ($1/\sqrt{n} = 0.053$)							

* The values of $1/\sqrt{n}$ give estimates of the standard deviations of the correlation coefficients when they are small.

the 218 girls, one has for the mean -0.0039 (which is not significant, being equal only to its standard deviation). The square of the standard deviation of the residuals from the weight table about this mean is $\sigma_v^2 = 0.003201$, a reduction from $\sigma^2 = 0.005321$ for the group as a whole irrespective of weight. If a regression equation is fitted

$$c - 3.0769 = 0.3612\ (w - 1.5794)$$

to the group, the value of the square of the standard deviation of the residuals therefrom is $\sigma_v^2 = 0.003079$, which is somewhat less than 0.003201.

In table 9 are given the values of σ_c^2 for the groups, the regression coefficient against weight, with its standard deviation below it, and the square, σ_v^2, of the standard deviation of the residuals of c from the regression equation. Next are given similar values for the regression against height, then similar ones for the two variable regressions against weight and height and, finally, similar results for the variables w, h and A and for w, h, A and P when the pulse rate is known.

14. VARIATION OF THE REGRESSION COEFFICIENTS

The standard deviations of the regression coefficients for the expression of c in terms of w and h are larger than for the expression of c in terms of other variables. This is due to the high correlation between w and h and the consequent high negative correlation between the "unknowns," which are the regression coefficients. Indeed, to get a true picture of the similarity of these coefficients it is important to take acount of the correlation between them. The examination may be made by considering the change in σ_v^2 when the regression coefficients are altered from their least squares values, say α and β, respectively, to other values, α' and β'. The increase of σ_v^2 is the mean value of $(c - c')^2$, c being the calculated least squares fit $\alpha w + \beta h$ and c' another expression $\alpha' w + \beta' h$ linear in the variables. Now

$$\overline{(c - c')^2} = \Delta\sigma_v^2 = \sigma_w^2 (\alpha' - \alpha)^2 + \sigma_h^2 (\beta' - \beta)^2 + 2r_{wh}\sigma_w\sigma_h (\alpha' - \alpha)(\beta' - \beta)$$

This is an ellipse in the plane of α', β' concentric with the least squares values α, β. The axes of the ellipse are determined by the values of λ, which satisfy the equation

$$\begin{vmatrix} \sigma_w^2 - \lambda & r_{wh}\sigma_w\sigma_h \\ r_{wh}\sigma_w\sigma_h & \sigma_h^2 - \lambda \end{vmatrix} = 0$$

and for the axes the value of the quadratic form $\Delta\sigma_v^2$ is simply

$$\overline{(c - c')^2} = \Delta\sigma_v^2 = \lambda [(\alpha' - \alpha)^2 + (\beta' - \beta)^2]$$

The directions of the axes are $(\sigma_w^2 - \lambda)(\alpha' - \alpha) + r_{wh}\sigma_w\sigma_h (\beta' - \beta) = 0$, so that if one plots β' vertically and α' horizontally, the inclination of the axes is

$$\theta = -\tan^{-1}\frac{\sigma_w^2 - \lambda}{r_{wh}\sigma_w\sigma_h}, \text{ or } \tan\theta = -\frac{\sigma_w^2 - \lambda}{r_{wh}\sigma_w\sigma_h}$$

Table 10 gives for the various groups the values of λ, the value of $\tan\theta$ and of $180° - \theta$ for the major axis and, finally, the value of the major axis itself if the ellipse is to contain one-half the observations (on the basis of normal distribution and the usual formulas for standard errors).

TABLE 9.—*Regression Coefficients, with Their Standard Errors and with Residual Variance for Groups I to XV When Weight, Height, Weight and Height, Weight, Height and Age or the Last Three with Pulse Rate Are Taken*

		Weight Alone		Height Alone		Weight and Height			Weight, Height and Age				Weight, Height, Age and Pulse Rate				
Group	$100\,\sigma_c^2$	w	$100\,\sigma_v^2$	h	$100\,\sigma_v^2$	w	h	$100\,\sigma_v^2$	w	h	a	$100\,\sigma_v^2$	w	h	a	P	$100\,\sigma_v^2$
I	0.2892	0.3501 ±0.0815	0.2175	1.103 ±0.263	0.2203	0.2238 ±0.2100	0.441 ±0.675	0.2159	0.3008 ±0.0839	0.638 ±0.266	−0.00768 ±0.00210	0.2080	0.1759 ±0.0632	0.891 ±0.158	−0.00506 ±0.00125	0.002782 ±0.000194	0.1678
II	0.2601	0.7243 ±0.1564	0.1400	1.640 ±0.494	0.1805	0.6284 ±0.2316	0.366 ±0.644	0.1381	0.7101 ±0.1525	0.151 ±0.423	−0.01249 ±0.00434	0.1182	0.7231 ±0.1367	0.141 ±0.379	−0.01221 ±0.00389	0.000835 ±0.000612	0.0941
III	0.2810	0.3749 ±0.0685	0.2058	1.116 ±0.219	0.2134	0.2881 ±0.1571	0.303 ±0.493	0.2049	0.5336 ±0.0795	0.582 ±0.180	−0.01620 ±0.00115	0.1387	0.4895 ±0.0423	0.655 ±0.127	−0.01411 ±0.00085	0.001453 ±0.000173	0.1271
IV	0.1140	0.3045 ±0.0834	0.1002	0.888 ±0.210	0.0962	0.1281 ±0.1117	0.663 ±0.287	0.0949	0.1536 ±0.0824	0.632 ±0.209	−0.00116 ±0.00063	0.0932	0.1936 ±0.0827	0.636 ±0.205	−0.00108 ±0.00062	0.000662 ±0.000310	0.0909
V	0.3830	0.6189 ±0.0797	0.1381	1.953 ±0.382	0.2156	0.5749 ±0.1313	0.214 ±0.504	0.1374	0.5885 ±0.0818	0.152 ±0.315	−0.00210 ±0.00151	0.1346	0.5093 ±0.0742	0.243 ±0.280	−0.00185 ±0.00140	0.001956 ±0.000401	0.1048
VI	0.1305	0.5792 ±0.0920	0.0866	1.245 ±0.202	0.0982	0.4681 ±0.1375	0.371 ±0.344	0.0853	0.4493 ±0.0925	0.440 ±0.234	+0.00174 ±0.00102	0.0838	0.4366 ±0.0886	0.483 ±0.224	+0.00243 ±0.00099	0.000850 ±0.000240	0.0781
VII	0.1214	0.4577 ±0.1015	0.0798	1.229 ±0.236	0.0841	0.3029 ±0.1242	0.600 ±0.352	0.0757	0.3215 ±0.1042	0.590 ±0.287	+0.00137 ±0.00186	0.0751	0.3540 ±0.0856	0.765 ±0.237	+0.00314 ±0.00156	0.001942 ±0.000337	0.0541
VIII	0.1167	0.3397 ±0.0626	0.0960	0.980 ±0.183	0.0931	0.1628 ±0.0872	0.664 ±0.235	0.0908	0.1767 ±0.0612	0.648 ±0.164	−0.00115 ±0.00055	0.0894	0.2005 ±0.0595	0.699 ±0.160	−0.00098 ±0.00054	0.000966 ±0.000230	0.0842
IX	0.1302	0.3240 ±0.0762	0.0961	0.942 ±0.223	0.0964	0.1834 ±0.1262	0.513 ±0.368	0.0925	0.1135 ±0.0682	1.399 ±0.242	−0.01138 ±0.01823	0.0720	0.1127 ±0.0493	1.396 ±0.176	−0.01138 ±0.00130	−0.000018 ±0.000180	0.0720
X	0.1125	0.3245 ±0.0818	0.0701	1.180 ±0.259	0.0626	−0.1423 ±0.2694	1.637 ±0.904	0.0620	−0.1542 ±0.0818	1.507 ±0.287	+0.00251 ±0.00168	0.0614	−0.1110 ±0.0489	1.499 ±0.164	+0.00163 ±0.00103	0.000264 ±0.000084	0.0607
XI	0.1410	0.4691 ±0.0709	0.0907	1.253 ±0.241	0.1050	0.3664 ±0.0926	0.497 ±0.292	0.0874	0.3881 ±0.0700	0.474 ±0.211	−0.00451 ±0.00201	0.0845					
XII	0.5320	0.3612 ±0.0287	0.3079	1.084 ±0.086	0.3077	0.1840 ±0.0889	0.561 ±0.267	0.3016	0.1922 ±0.0288	0.642 ±0.092	−0.00203 ±0.00086	0.3008					
XIII	0.6165	0.4110 ±0.0513	0.3840	1.210 ±0.161	0.4021	0.3488 ±0.1537	0.203 ±0.471	0.3832	0.3972 ±0.0522	0.447 ±0.165	−0.00694 ±0.00148	0.3743					
XIV	0.5260	0.4104 ±0.0784	0.2872	1.219 ±0.242	0.2967	0.2776 ±0.2313	0.429 ±0.701	0.2840	0.3502 ±0.0889	0.440 ±0.243	−0.00453 ±0.00241	0.2820					
XV	0.5720	0.3707 ±0.0230	0.3312	1.066 ±0.076	0.3685	0.2910 ±0.0432	0.294 ±0.135	0.3269	0.3071 ±0.0233	0.442 ±0.085	−0.00371 ±0.00115	0.3242					

The high degree of constancy of the value of tan θ is to be noted; it means that the major axes of the ellipses are essentially parallel and that there is relatively little change in σ_v^2 for any of the groups if the regression coefficients are altered by $\Delta\alpha$ and $\Delta\beta$ provided $\Delta\beta = -3.5\,\Delta\alpha$ or thereabouts.

15. RELATION TO THE DU BOIS BODY SURFACE FORMULA AND TO AGE

Now, the basal metabolism was early expressed in terms of the body surface where $s = 0.425w + 0.725h +$ constant. The coefficients of w and h were chosen in fitting the measured surfaces to the weights and heights (all in logarithms) in such a manner that $3\alpha + \beta = 2$; i. e., if in ordinary metric measure (not logarithms) $S = 71.84\ W^{0.425}\ H^{0.725}$, the "dimensions" of S are 2 provided W is considered [27] to be

TABLE 10.—*Parameters and Major Axes of the Ellipses Which Contain Half the Observations*

Group	λ_1	λ_2	Tanθ	180°-θ	Major Axis
I	0.000080	0.006332	−3.44	73.8	0.81
II	0.000130	0.002456	−3.60	74.5	0.75
III	0.000096	0.003294	−3.43	73.7	0.36
IV	0.000111	0.001601	−3.48	74.0	0.12
V	0.000157	0.006671	−4.74	78.1	0.59
VI	0.000086	0.001434	−3.15	72.4	0.42
VII	0.000107	0.002127	−3.67	74.7	0.49
VIII	0.000110	0.00.924	−3.52	74.1	0.29
IX	0.000126	0.003502	−3.50	74.1	0.44
X	0.000028	0.004360	−3.48	74.0	1.06
XI	0.000126	0.002390	−4.56	77.6	0.35
XII	0.000178	0.018932	−3.13	72.3	0.32
XIII	0.000150	0.015063	−3.55	74.3	0.58
XIV	0.000164	0.015536	−3.19	72.6	0.84
XV	0.000467	0.018854	−3.59	74.4	0.16

27. The formula for S was obtained by fitting to measurements of S, W and H for 9 persons, of both sexes, ranging in age from infancy to maturity. The introduction of the constraint $3\alpha + \beta = 2$ so as to make the dimensions of S 2 if W be considered of dimensions 3 may or may not be wise; there are surely statistical differences between body weight and body volume, because not all persons are of the same specific gravity. We have refitted the original data by least squares (using logarithms of all three variables) and without imposing the constraint. We found

$$s - \bar{s} = 0.420\ (w - \bar{w}) + 0.681\ (h - \bar{h}) \text{ or } S = 91.35\ W^{0.420}\ H^{0.681}$$

The sum $3\alpha + \beta = 1.94$ is not much changed from 2, and the multiplier 71.84 is changed by 30 per cent, to 91.35. The fit is much improved; for σ_v for s is 0.00564 for our fit as compared with the value 0.00904 for the Du Bois formula. (If one fits with the constraint $3\alpha + \beta = 2$ one finds $\alpha = 0.443$, $\beta = 0.670$ and the multiplier 88.40 with $\sigma_v = 0.00873$.) In respect to the differences between the values of the constants, the correlation between the unknowns α and β is high, since $r_{wh} = 0.9294$, and thus considerable differences in α and β do not make much difference with σ_v^2 if the variations are of the proper relative magnitudes. If one writes $s = \alpha w +$

(Footnote continued on next page)

of dimensions 3. The ratio of basal calories per square meter per hour to the body surface, S, varied according to sex and age, decreasing with age. (The standards were given for ages above 14.) One should therefore not omit the age variation in making the comparisons; but if one does, the evidence is that the sum of $3\alpha + \beta$ is not 2, but less than 2. In figure 8 are plotted the values of α and β for the different groups and the directions of the greatest indetermination of the quantities.[28] The lines are essentially parallel and also nearly parallel

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$\beta h + \gamma$ with a constant term, the change in σ_v^2 for s in going over from least square values to others will be

$$\overline{(s - s')^2} = (\Delta\alpha)^2 \overline{w^2} + 2\Delta\alpha\Delta\beta\overline{wh} + (\Delta\beta)^2 \overline{h^2} + 2\Delta\alpha\Delta\gamma\overline{w} + 2\Delta\beta\Delta\gamma\overline{h} + (\Delta\gamma)^2$$

The ratios of $\Delta\alpha : \Delta\beta : \Delta\gamma$ for which this change is least are $1 : -2.88 : 4.66$ and the increase $\Delta\sigma_v^2$ above the least squares values of 0.000032 by changing the variables in these proportions is $0.017\ (\Delta\alpha)^2$. Thus a change of $\Delta\alpha = 1 \pm 0.033$ with $\Delta\beta = -0.096$ and $\Delta\gamma = +0.155$ will only increase σ_v^2 to 0.000050, which is considerably less than the value given with the constraint $3\alpha + \beta = 2$. One might therefore write

$$S = 64\ W^{0.387}\ H^{0.777} \text{ or } S = 130\ W^{0.453}\ H^{0.585}$$

without making a serious difference with the goodness of the fit. For this considerable change in the formula the value $3\alpha + \beta$ remains practically at 1.94. Of course, if one fitted expressions of this type (instead of using logarithms) the results might be somewhat different because of different weighting. Which way one should fit would depend on how the deviation actually behaved, i. e., on whether percentage change or actual change in S, W and H represented the physically significant facts.

28. If the expression for the calories for any group is $C = KW^\alpha H^\beta$ or $c = \alpha w + \beta h$, with a reasonable leeway between α and β without seriously affecting the fit, it may be possible to shift α and β to nearby values, α' and β' so that $C = K'W^{\alpha'}H^{\beta'}$ when compared with $S = LW^\gamma H^\delta$ gives merely a power of S as $C = \text{constant } S^p$. Thus, if we take group I with $\alpha = 0.224$ and $\beta = 0.441$, we note that the ratio $\beta : \alpha$ is not the same as $\delta : \gamma$ for the body surface formula whether we take the Du Bois values or our own. If we choose the latter, viz., $\delta = 0.681$ and $\gamma = 0.420$, shifting to $\alpha' = 0.239$ and $\beta' = 0.389$, which is of small amount and in the direction in which the fit deteriorates least rapidly $(\Delta\beta : -3.44\Delta\alpha)$, we find $p = 0.57$ and may write $C = \text{constant } S^{0.57}$. If we choose the Du Bois values $\delta = 0.725$ and $\gamma = 0.425$, we should find $\alpha' = 0.235$, $\beta' = 0.403$, $p = 0.55$ and $C = \text{constant } S^{0.55}$. This whole discussion can be handled quickly by a sort of graphic method on the basis of a figure such as figure 8. If in that figure we should draw from the origin a line $\beta = (\delta/\gamma)\alpha$, this line would cut the direction of the major axis of the ellipse centered at (α, β) in the point (α', β') to which α, β would have to be shifted if $\beta' : \alpha'$ were to be as $\delta : \gamma$ and then $\alpha : \gamma$ would be the value of p. Figure 8 gives the centers and major axes for groups from I to XV (except for X) and the lines $\beta = 1.62\alpha$, which correspond to our fit to the Du Bois data, and $\beta = 1.3\alpha$ and $\beta = 2.0\alpha$, which correspond to the two variations[27] from our own fit which still leave the expression S very well fitted. It is geometrically clear that for the leeway there is to α and β in samples of the size we have there is no serious difficulty in expressing C as a power of S, but this power would not be the first power; it would vary for the different groups from about 0.5 (for groups IV and IX) to about 1 (for groups II and V). Indeed, an approximate value for p may be found from the lowest line of table 11 by dividing the numbers by 2.

to $3\alpha + \beta = 2$. As the minor axes of the ellipses are the directions in which the fit becomes most rapidly worse, the different groups differ in the diagram chiefly by the sidewise displacement of the points, and the relation $3\alpha + \beta = 2$ cannot be considered as at all satisfied. Groups II, IV, V, VI, VII, VIII and XI are of the age range above 14, like those used for the Aub-Du Bois table, whereas Groups XII, XIII, XIV and XV are mainly below the age of 14 and groups I, III, IX and X run squarely across the age 14.

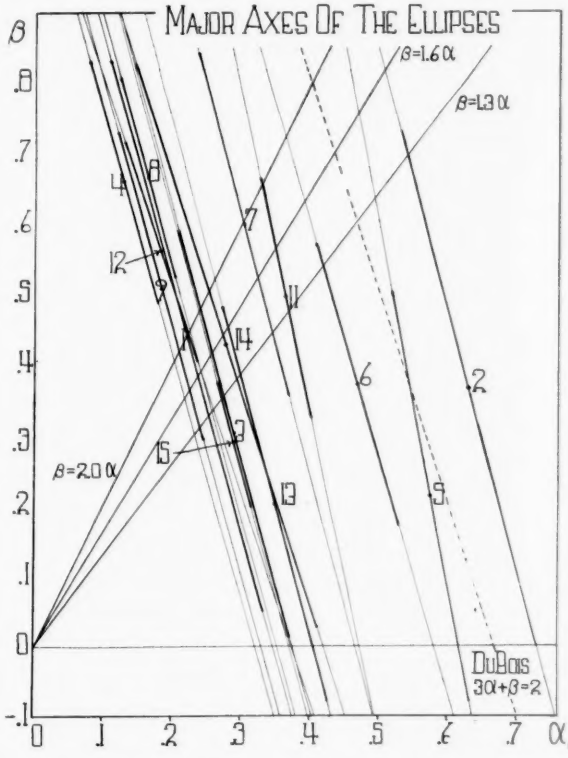

Fig. 8.—Plot showing the directions of the lines along which the linear regression coefficients α and β of the fit of (logarithmic) calories to (logarithmic) weights and (logarithmic) heights may be displaced with the minimum disturbance of the goodness of fit for each of groups I to XV (except X), numbered in Arabic numerals. The heavy part of the lines designates the major axes of the ellipses of equal frequency within which half the values (α, β) would lie according to the usual formulas of sampling theory. The line $3\alpha + \beta = 2$ appropriate to the Du Bois surface formula is the dotted line on the right. The significance of the three diagonal lines through (0,0) is explained in footnote 28. The minor axes of the ellipses could not be indicated without great confusion; they are relatively small, showing that although (α, β) may be displaced rather freely along the major axes, the displacement perpendicular thereto is severely restricted.

If one examines the regression coefficients on w, h and A, one finds that in the main the coefficients of age are negative, indicating that basal metabolism decreases with age. The decrease in the Aub-Du Bois table for the ages from 14 to 20 years is about 3 per cent per year, which corresponds to a trend coefficient on age of about -0.014; there are only two groups (II and III) with any such magnitude in our list. If one takes the seven groups which are mainly in the range above 14 years of age, the mean (without weighting according to the number of persons in the list or according to the reciprocals of the squares of the standard errors of the coefficients) is -0.0031. If one takes the combined groups of Lucas, which are of the earlier ages, the value is -0.0037, whereas the unweighted average for the three groups considered is -0.0045. If one takes the four groups for which the ages range squarely from below to above 14, the mean is -0.0051. Thus, so far as the partial correlation (or least squares) method is applicable to the considerable number of groups we are discussing, which contain a very large number (853) of girls, there is no indication that the age correction is at all of the magnitude of a decrement of 3 per cent per annum; rather does it seem to be about a third as much.

It should, however, be remarked that the three regression coefficients on w, h and A are correlated and that considerable changes may be made in them without seriously affecting the fit (seriously increasing σ_v^2), provided the changes are properly adjusted to lie along or nearly along the major axis of the ellipsoid

$$\Delta\sigma_v^2 = (a'-a)^2\,\sigma_w^2 + (\beta'-\beta)^2\,\sigma_h^2 + (\gamma'-\gamma)^2\,\sigma_A^2 + 2r_{wh}\sigma_w\sigma_h\,(a'-a)\,(\beta'-\beta) + 2r_{wA}\sigma_w\sigma_A\,(a'-a)\,(\gamma'-\gamma) + 2r_{hA}\sigma_h\sigma_A\,(\beta'-\beta)\,(\gamma'-\gamma)$$

where a, β and γ are the least squares values of the regression coefficients on w, h and A, respectively. That the latitude for a, β and γ is decidedly less than for a and β when weight and height alone are used may be seen at once from the fact that the standard errors of the coefficients are decidely less. The sum $3a + \beta$ is again not 2; i. e., the introduction of age as a variable by the partial correlation method does not seem to make the dependence of the value for the basal metabolism on the weight and height much nearer that which would be taken from the body surface relation of Du Bois.

Table 11 lists $(3a + \beta)$, the sum of three times the weight regression coefficient plus the height regression coefficient with and without age correction.

The results for groups I, III, IX, XIII and XIV are somewhat improved, that for group X is made worse and those for the other groups are not materially changed.

16. PULSE RATE

For the groups for which the pulse rate is also known, except groups II and IX, the regression coefficient on pulse rate is highly significant but in amount is decidedly variable, ranging from 0 to 0.0028 per pulse beat per minute. The value for group I (57 girls of Talbot's series) is the largest but is not much larger than that for groups V and VII. The introduction of the additional variable, pulse rate, in the main reduced the negative effect of age—at least so far as concerns the groups under discussion.

Looking back over the whole table with especial reference to the comparative values of σ_v^2, one observes that in the fifteen groups the regression on weight generally gives a better fit than that on height, as might be expected. When both weight and height are used as variables there is relatively little improvement in the fit as compared to that when weight alone is used. The greatest improvement appears to be in group IX, but in some cases the improvement seems less than that which the additional constant would ordinarily encompass. The

TABLE 11.—*Values of the Sum of Three Times the Weight Coefficient Plus the Height Coefficient*

Group	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
w, h and A.....	1.54	2.28	2.18	1.09	1.92	1.79	1.55	1.18	1.74	1.04	1.64	1.22	1.64	1.49	1.36
w and h.....	1.11	2.24	1.17	1.05	1.94	1.78	1.51	1.15	1.06	1.21	1.60	1.18	1.25	1.26	1.17

introduction of the further variable, age, brings, on the whole, little further improvement in the fit—exceptions are seen in groups III and IX. The introduction of the pulse rate as a variable produces a decrease in σ_v^2 of 20 per cent or more in groups I, II, V and VII but practically no decrease in groups IV, IX and X.

17. INTRODUCTION OF THE CONSTANT TERM

It should be noted that for all these data on regression equations for the fifteen groups (see section 22), the equations for each group were referred to the means of the groups, whereas the general regression equation in the variables would be of the form

$$c = \alpha w + \beta h + \gamma A + \ldots + k$$

with a constant k. As a matter of practical convenience it would be desirable to have the regression in this form and thus give an estimate for c from measures w, h, A, ... For any particular group the value of k may, of course, be expressed in terms of the other regression coefficients and the means of the variables of the group as

$$k = \bar{c} - \alpha \bar{w} - \beta \bar{h} - \gamma \bar{A} - \ldots$$

There will be correlations between the constants α, β, γ, ... k and a preferential direction $d\alpha : d\beta : d\gamma : \ldots : dk$ along which the increase

of σ_v^2 from the minimum value will be slowest. Under favorable arithmetical circumstances considerable variations in the values of the constants, if in the right proportions, might not make a large difference in σ_v^2. We have discussed the change $\Delta\sigma_v^2$ in σ_v^2 for a change of the regression coefficients α, β and γ,... and it may readily be shown that the additional change in σ_v^2 is merely

$$\Delta_2\sigma_v^2 = (\alpha'\bar{w} + \beta'\bar{h} + \gamma'\bar{A} + \ldots - \bar{c})^2$$

To illustrate what happens, one may return to the case in which the variables were w and h and in which the results despite the differences in the regression coefficients of c on w and h in the different groups were not really very discordant. If one takes group I as standard, with values $\alpha = 0.2238$, $\beta = 0.4409$, $k = 1.8066$ and $\sigma_v^2 = 0.002159$, and uses α' and β', as determined for certain other groups relative to their means, one finds certain increases in σ_v^2 (for

TABLE 12.—*Changes in the Goodness of Fit When Constants of Various Groups Are Used for Group I and When the Constants for Group I Are Used for the Data of Various Groups*

Group	k	$\Delta\sigma_v^2$	$\Delta_2\sigma_v^2$	$\Delta\sigma_v^2$	$\Delta_2\sigma_v^2$
I	1.8066	0	0	0	0
II	1.2478	0.00086	0.00109	0.00034	0.00016
IV	1.4045	0.00001	0.00590	0.00001	0.00616
IX	1.6976	0.00000	0.00040	0.00000	0.00040
X	−0.2555	0.00013	0.00280	0.00005	0.00068
XIV	1.7232	0.00002	0.00034	0.00004	0.00036
XV	1.9838	0.00001	0.00099	0.00005	0.00120

group I), which are tabulated as $\Delta\sigma_v^2$; the values of the additional change $\Delta_2\sigma_v^2$ when the constant k′ is also substituted for k are as indicated. One may also substitute the values of α and β for group I in the regression equations of the other groups and find for those groups the increased $\Delta\sigma_v^2$ and $\Delta_2\sigma_v^2$ owing to the use of these constants with and without the corresponding change in k.

As $\sigma_v^2 = 0.002159$, we may consider that something like 0.00004 is a tolerable change. Then the constants of α' and β' for groups IV, IX, XIV and XV may be taken in place of α and β in group I without difficulty, or the values α and β of group I may be used in place of the values α' and β' in the various groups, provided the means of group I are maintained; but if the means are changed to those of the respective groups, i. e., if the constant k is changed to the indicated value, the values of $\Delta_2\sigma_v^2$ are so large as to be quite intolerable. Thus it appears clear that one cannot use any general linear expression to represent c.

18. CORRECTION OF CALORIES FOR EXCESS WEIGHT AND FOR AGE

Reference has been made to the correction of calories for weight (table A) due to the percentage of deviation of weight from that estimated from height (see section 27, part 3).[29] For a large number of cases collected from the literature the data are shown in table 13, divided into two groups,[30] XVI and XVII, according to the age range of the subjects. The entries under "Percentage of Excess Weight" are on a geometric scale because of use of logarithms for Δw; the entries under "Mean Percentage of Excess Calories" are the means Δc of excess logarithms over mean logarithm. The means of the two groups are unlike, the first group being as a whole in line with our tabular standard and the second being well below it. The difference might be expected because of the effect of age. Our table 3*A* was graduated from data on girls most of whom were under 18 years of age, and most of the second group were over that age. A differential result of 14.7 per cent for the mean age difference of 8.2 years is only 1.8 per cent per annum. The trend coefficients are -0.24 for group XVI and -0.28 for group XVII, which may be compared with -0.22 for our standard series. This may be considered reasonably satisfactory agreement and might indicate some such correction as $\Delta c = -0.25\,\Delta w$ for excess weight for height by our standard. The corrections according to this formula would be as follows:

Percentage of excess weight....	−45	−30	−15	0	+15	+30	+45	+60
Percentage of excess calories...	+16.1	+ 9.3	+ 4.1	0	− 3.4	− 6.3	− 8.9	−11.1

29. One may note that in the table the last value in each group tends to revert from the trend established by the rest. Such reversion in individual cases means nothing owing to the wide individual variations from any standard. However, for 12 measurements (in a series of Dr. Talbot's) on 11 persons of ages from 5 to 15 (which should make them comparable to group XVI rather than to group XVII) who were excessively obese (46 per cent, on the average), the mean percentage correction of calories for weight was + 1.1 per cent; i. e., this small group had no significant average correction of calories as examined from weight despite the great average excess weight of the subjects. In view of the great individual variations, a group of 12 measurements is too small to use as a base for statistical conclusions, but for the different individual determinations there were negative corrections to be applied for some of the less obese girls, whereas there were only positive corrections for the more obese, making it look as though there might really be a reversal in the sign of the correction (relative to the mean) for the most obese, as indicated by the single final observations in the two large groups.

30. In group XVI are observations by Blunt (83), McLeod (83), Stark (80), Lucas (359) and Talbot (102) on underweight and overweight persons who were normal except as to weight for height. In group XVII are observations by Coons (213), Tilt (52), Remington and Culp (48) and Stark (97) on underweight, overweight and normal persons. These five groups were made up from the smaller series in such a manner as to get the largest practicable degree of homogeneity for each of the large groups.

In applying such corrections, allowance for age is necessary, as indicated by the difference in the means found above.

With respect to corrections for age,[31] it should be remarked that those of Aub and Du Bois are not linear on age, the figures being:

Age	14–15	16–17	18–19	20–29	30–39
	43.0	40.0	38.0	37.0	36.5
Decrease	3.0	2.0	1.0	0.5	
Per annum	1.5	1.0	0.1	0.05	

If the decrease were logarithmic, one should use a=log A as the variable, possibly by measuring A from —0.75 years; we have used A in years because we have been interested chiefly in narrow ranges of ages. When we eliminated from groups XVI and XVII the data for all girls whose

TABLE 13.—*Percentage of Excess Calories According to Percentage of Excess Weight for Two Groups of Data*

	Group XVI		Group XVII	
	$\bar{A} = 11.9, \sigma_A = 2.6$		$\bar{A} = 20.1, \sigma_A = 2.9$	
Percentage of Excess Weight	n	Mean Percentage of Excess Calories	n	Mean Percentage of Excess Calories
—41.7	1	18.7	..	.....
—31.5	1	3.4	1	—15.8
—26.6	6	8.3	..	.....
—21.4	20	4.9	6	—12.8
—15.8	73	4.1	24	—11.8
— 9.6	122	2.4	56	—13.1
— 3.4	143	1.3	76	—13.3
+ 3.4	137	0.9	79	—13.6
+10.8	102	— 2.8	68	—14.7
+18.7	50	— 3.0	40	—16.8
+27.2	35	— 3.0	33	—14.0
+36.3	10	— 2.7	13	—18.0
+46.0	6	— 9.8	7	—15.8
+56.5	1	+10.8	2	— 9.7
+67.7	..	....	4	—18.6
+97.0	..	....	1	— 9.7
Total	707	0.6	410	—14.1

31. Carpenter, T. M.: Ohio J. Sc. **33**:297-334, 1933. On pages 327 to 329 Carpenter gives data on 1 woman and 3 men over a wide range of age and on a group of elderly women. He discusses the effect of age on basal metabolism, with the conclusion that "many more observations are needed to establish the variations in the effect of age on the metabolism of the individual." According to our standard, the group of 23 elderly women (ages from 66 to 86) had an average basal metabolic rate referred to weight of —25 per cent, that of the younger half being —23 per cent and that of the older half —28 per cent. This represents a decrease of 0.5 per cent per annum for this group and of about 0.4 per cent per annum for the whole group as compared with our standard for a girl in her teens. Whether a correction of —0.4 per cent per annum for females from 16 years to the end of life would really be satisfactory is one of those questions concerning which the quoted remark of Carpenter seems to be applicable. One may also consult an article by F. G. Benedict (New England J. Med. **212**:1111, 1935).

weight lay outside the normal limits, — 10 per cent and + 20 per cent, by the Baldwin-Wood standard and tabulated by age, we had the data shown in table 14.

There appears from the table to be no significant decrease for the range of ages from 8 to 13, but a general positive correction as compared with our weight standard for calories; for ages from 13 to 20 in group XVI the corrections are all negative but without any conspicuous trend in view of the large sampling errors which would apply to the last two items. In group XVII the corrections are all negative and large, with probably a slight downward trend toward larger negative values with increasing age; the two groups appear not comparable

TABLE 14.—*Percentage of Excess Calories According to Age for the Normal Subjects of Two Groups*

	Group XVI		Group XVII	
Age	n	Mean Percentage of Excess Calories	n	Mean Percentage of Excess Calories
8.5	88	2.0	..	.....
9.5	38	3.1	..	.....
10.5	58	1.4	..	.....
11.5	62	2.4	..	.....
12.5	60	3.5	..	.....
13.5	42	—3.4	..	.....
14.5	45	—5.7	..	.....
15.5	25	—6.5	..	.....
16.5	26	—2.9	2	—18.6
17.5	17	—3.4	40	—11.6
18.5	3	—11.8	53	—11.6
19.5	1	—9.7	64	—14.6
20.5	..	...	48	—13.8
21.5	..	...	15	—16.9
22.5	..	...	11	—18.9
23.5	..	...	11	—16.3
24.5	..	...	6	—16.7
25.35	..	...	12	—16.2
	465	+0.1	262	—14.0

for the ages which overlap because, as has been shown (see section 22), the height of the heat production is at a different level in different localities. It may be remarked again that our graduation was from data on younger persons than those in group XVII and might well have systematic corrections when applied to older persons; it may also be remarked once more that as all the variables are correlated (particularly for the younger ages) the application of successive corrections is far from satisfactory.

19. FIGURES FOR SOME PATHOLOGIC CONDITIONS

We have treated girls who were normal by the Baldwin-Wood standard with a short discussion of some who were overweight or underweight but were considered clinically normal. We have three small groups of data on girls with a pathologic condition: (*a*) measurements

on 24 cretins, (*b*) 11 measurements on 10 girls with hyperthyroidism and (*c*) 24 measurements on 24 obese girls with signs of pituitary disease.

(*a*) The cretins were in the age group from birth to 7½ years, covered by the Benedict and Talbot normal standards (see section 28, part 1). They averaged 10 per cent overweight on the basis of our standard. Calories from weight relative to our standard ran from — 52 per cent to — 10 per cent, with an average (logarithmic) of — 30.3 per cent; calories from height ran from — 48 per cent to + 11 per cent, with an average of — 24.5 per cent.

(*b*) The girls with hyperthyroidism were in the age group from 5 to 12 years (see section 28, part 2). They averaged — 8 per cent overweight (8 per cent underweight) by our standard. Calories from weight ran from + 6 per cent to + 59 per cent, with an average of + 25.0 per cent; calories from height ran from + 4 per cent to + 48 per cent, with an average of + 21.3 per cent. The pulse rate averaged 96.

(*c*) The obese girls with signs of pituitary disorder were between the ages of 1 and 15 years. They averaged 47 per cent overweight. Calories from weight ran from — 32 per cent to + 19 per cent, with one extraordinary value of + 145 per cent; the (logarithmic) average is + 2.1 per cent when the very large value is included. Calories from height ran from — 10 per cent to + 68 per cent, with an average of 28.6 per cent.

In figure 9 are plotted the four points which show the values of the average excess calories from weight and from height for the cretins, C, for the girls with hyperthyroidism, H, for the girls with pituitary disease, P, and for the normal obese girls, O—the origin being N and representing the averages (zero) for normal girls. C, N and H lie essentially in a straight line, which, incidentally, is about coincident with the direction of the flock of points in figure 7 representing the relation of excess calories from weight and from height for the 179 basic measurements. It may be noted that considering the variability in this sample the points P and O are practically coincident.

20. STATISTICS AND CASE HISTORIES

Statistics are developed for the purpose of describing the properties of groups and for comparing different groups; they shed little light on the situation of the individual. The great mass of persons lie near the mean, but scattered subjects lie well away from it without failing to be fair members of the group. If one takes for the 465 normal persons of group XVI the residual calories from our weight standard, the mean is — 0.1 per cent and the standard deviation 0.0494 (logarithmic).

covering a range from — 10.8 per cent to + 12 per cent within which approximately two thirds of the measurements fall. If one allows a range of twice the standard deviation about the mean, the percentages run from — 20.3 per cent to + 25.5 per cent, and within these limits practically 95 per cent of all the measurements lie. There remain, however, some 5 per cent of the measurements more scattered from the mean than this, the total range being from — 27 per cent to + 46 per cent. This is an entirely characteristic regularity in statistical behavior. One can readily see, however, that this range in the deviations of normal persons from the tabular standard seriously overlaps the measurements of some of the abnormal persons. Thus, of the 24 cretins,

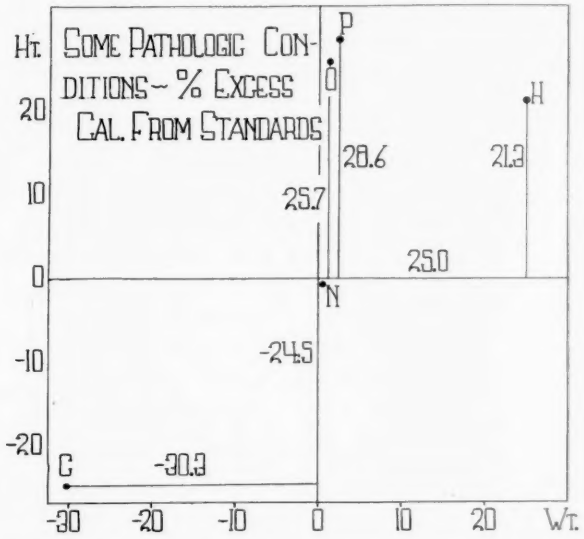

Fig. 9.—Plot of mean percentage excess calories from the weight and height standards individually for cretins (C), normal girls (N) and girls with hyperthyroidism (H), showing that these three points lie essentially on a line, and for normal excessively obese girls (O) and obese girls with signs of pituitary disorder (P), showing their essential identity of position, with characteristic displacement from the line CNH.

5 had a basal metabolic rate higher than the minimum figure for the normal group, and the rate of 5 of the 11 girls with hyperthyroid disease fell within the normal range. Of course, as a person departs from the mean the chances that he is properly in the normal group diminish. We have not enough data on persons with hyperthyroidism to say what the relative chances are that if a person is found to have a basal metabolic rate 25 per cent above the tabular standard for weight he is normal or hyperthyroid; the higher the rate above the mean, the more

likely it is that the subject is not normal but belongs in some abnormal classification. Figure 10 gives (vertically) the percentages of subjects whose values deviate from the mean by more than the percentages given as abscissas; the distribution of subjects is also given as a frequency distribution on the same abscissas.

When discussing distribution of a group one must bear in mind that different groups may differ not only in their means but in their standard

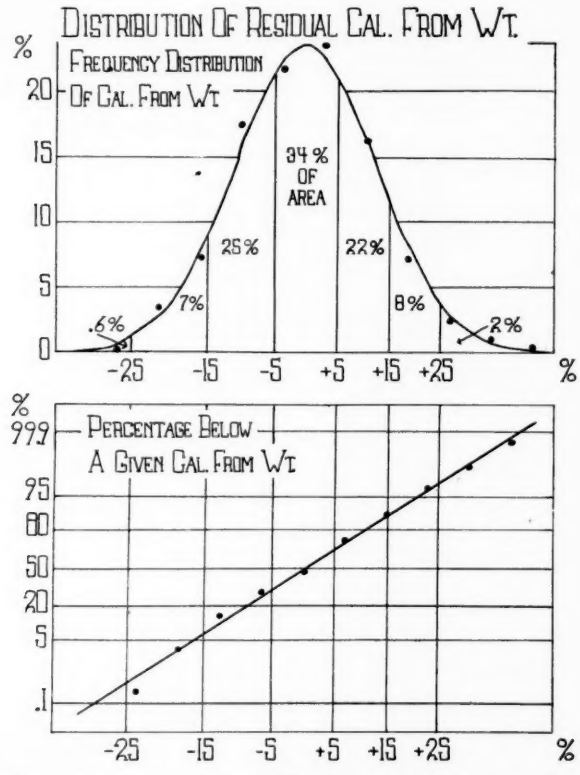

Fig. 10.—Plot of the frequency distribution of residual (logarithmic) calories from weight (plotted in logarithms but with the abscissas marked in percentages so that the distribution is symmetrical but the scale is asymmetrical), with the corresponding cumulative plot on probability paper, showing a high degree of rectilinearity. The figures are constructed from the data for 465 normal girls and show an excellent fit of the residuals to the "normal law of errors."

deviations and that, furthermore, they may differ in the corrections for various factors, such as pulse or age or excess weight for height, which may have been applied. It is therefore not feasible in the present state of knowledge to assign any particular diagram, such as figure 10, as being representative of what any particular physician will find as a

distribution of normal subjects in his practice or in his neighborhood. No values can as yet be formulated which will separate on a statistical basis the abnormal persons from the exceptional normal persons. One of the limitations of statistics, amply demonstrated in a variety of fields, is that the individual subject must be discussed chiefly on the basis of his own history, which covers many more details than have yet been incorporated into statistical discussions.

CLINICAL ANALYSIS

21. PULSE RATE

The earliest observations on metabolism showed that exercise, with its increased pulse rate, is associated with a higher metabolism than that found with the subject at absolute rest. The elevation in the pulse rate was secondary to the muscular exercise.

The question arose as to whether elevation of the pulse rate per se could cause an increase in the heat production. This separation of cause and effect is difficult because other factors, for example, nervousness, can cause an increase in the pulse rate. It is further complicated by the probability that visual observation of a subject does not give evidence of his minor muscular movements and his physical status.

Our figures (see section 7) show that the children in the private school group who had a high pulse rate had also a high metabolism, even though they were from the point of view of the operator physically absolutely quiet. There was roughly an increase of 8 calories per pulse beat. Topper's girls, on whom repeated observations were made over a period of months, showed individually that an increase in the pulse rate is associated with an increase in the metabolism. Curiously, there was an increase of 7 calories per unit increase of pulse rate up to 100 calories. As is mentioned in the section on puberty, Nylin found no connection between the pulse rate and the elevated metabolism of that period. The metabolism of his children was elevated during pubescence, and the pulse became slower.

There was no increase in the metabolism when there was an increase in the pulse rate of the girls of from 9 to 16 years studied by Stark (see section 12).

The irregularity in the relationship of pulse rate to metabolism in much of the reported data is contradictory and makes it obvious that this physiologic phase of the problem must be studied with greater care, with more controls and in a larger number of observations on individual subjects before a decision can be arrived at.

From the clinical point of view, the recorded pulse rates probably cannot be taken as an absolutely accurate measurement of the rate of

the pulse beats during the period in which the metabolism is being determined. The method commonly used to obtain the rate is to count the pulse at the wrist perhaps once during the period and once at the end. This gives no assurance of what takes place during the rest of the time. Further errors creep in when the pulse is counted for only fifteen seconds, for then there is a possibility of an error of 8 beats. Nothing is definitely stated in the published records concerning the technic of counting the pulse beats. Examples of the great variability in the pulse rate of new-born infants are illustrated in a publication of the Carnegie Institution of Washington.[6a] Variations of rate within sixty seconds are observed even in adults. The recorded pulse rates, therefore, can be considered only general indications of the heart beats and not accurate measurements.

With this in view, a markedly elevated pulse rate was considered an indication of failure to obtain a basal record. With our private school group a pulse rate of 15 or more above the expected normal level for the child was taken to indicate that the period was not basal. The period was automatically eliminated, and repeated tests were made when possible until a reasonable pulse rate, with other signs of basality, was obtained. Clinically, the ideal basal periods were obtained when the pulse rate averaged at about or near the expected rate for the age.

The pulse rate, therefore, cannot be taken too seriously unless it is automatically recorded through the whole period, as has been done in a few instances. Such accurate measurements, however, are possible only in the physiologic laboratory. General indications only are to be expected in the usual clinical investigation.

22. EFFECT OF CLIMATE AND RACE

The relatively low cost of the modern portable apparatus for determining metabolism and the ease of transporting and operating it extended its use to many remote parts of the world and to tropical climates. The results obtained in warm climates were different from those obtained in temperate countries, and the question arose as to whether racial peculiarities and differences might not be responsible for this. Du Bois [1] in an editorial review discussed the pros and cons of this question from the point of view of adults and concluded that racial differences are so slight that they are obscured by other factors.

Investigators have suggested that the metabolism of orientals is lower than that of Americans and Europeans. Benedict and Meyer [32] reported that the metabolism of 18 American-born Chinese girls averaged 9.2 per cent lower than the Harris-Benedict standard and 6.1 per cent

32. Benedict, F. G., and Meyer, M. H.: Chinese J. Physiol. **7**:45, 1933.

lower than the Aub-Du Bois standard. When the metabolic rates of these American-born Chinese girls is compared to our new standards for weight they average only 2 per cent less than that of the Boston girls (our new series) of the same weight; the difference is insignificant. Wang and Hawks' [33] American-born Chinese girls who were 9 years of age or older showed a metabolism identical with that of the American private school girls. The evidence, therefore, instead of being in favor of a racial difference between the heat production of Chinese and that of American girls is, on the contrary, against such a conclusion.

The heat production of 10 of Takahira's group of 16 girls, aged from 9 to 14 years, was within normal limts, and that of 6 was from + 16 to + 25 per cent above the rate for American girls of the same weight, while the heat production of Nakagawa's [34] 16 young girls, aged from 4 to 6½ years, whose metabolism was determined in a cot chamber and is comparable to that of the younger girls used for the new standards, averaged roughly 10 per cent higher than that of the American girls. Fourteen of these Japanese girls, from 7 to 11 years old, inclusive, excluding 2 with a metabolism of + 23 and + 26 per cent, respectively, had an average heat production 6 per cent higher than that of American girls of the same weight. These examples show that the metabolism of Japanese girls, if basal, is higher and not lower than that of American girls. Since it has the same trend as that of the girls studied by Lucas, we believe it is fair to say that there is no difference between the metabolism of Japanese and that of American girls of the same weight.

The Dutch girls under 50 Kg. in weight studied by de Bruin [35] had an average metabolism 15 per cent higher than that of American girls of 12 Kg.; this difference became gradually less and entirely disappeared at 50 Kg. Nylin [36] studied 12 girls in Stockholm with great care, making tests every three months for four years. The metabolism of these girls of from 9 to 14 years of age agreed with our prediction table for weight. Only 1 observation, of + 17 per cent, fell outside the usually accepted 10 per cent variation. The variations averaged — 0.4 per cent. The metabolism of Swedish girls is therefore the same as that of American girls.

33. Wang, C. C., and Hawks, J. E.: Basal Metabolism of Twenty-One Chinese Children Reared or Born and Reared in the United States, Am. J. Dis. Child. **44**: 69 (July) 1932.

34. Nakagawa, I.: Growth and Basal Metabolism: Basal Metabolism of Preschool Children, Am. J. Dis. Child. **47**:963 (May) 1934.

35. de Bruin, M.: Nederl. tijdschr. v. geneesk. **77**:5684, 1933.

36. Nylin, G.: Acta med. Scandinav., supp. 69, 1935, p. 1.

There is also evidence that the metabolism of Danish boys (Bierring [37]) between the ages of 7 and 18 years is the same as that of American boys weighing 70 Kg. or more.

More important evidence is available concerning adults, whose metabolism was determined in temperate climates and again in tropical climates. Martin [38] measured his own metabolism daily on a thirty-five day voyage from London to Australia and found that after encountering hot weather his metabolism began to fall, reaching its minimum on the fifth day of tropical heat, and remained low until the trade winds cooled the air. It then rose immediately to its former level. The maximum difference between the high and the low value was 12 per cent. Although daily variations of 5 per cent may be found in the heat production of normal persons, this result seems to indicate that climate, especially marked changes in the temperature of the air, have an effect on metabolism. Eleanor D. Mason [39] made a study of the metabolism of Indian women of Madras and of European women who had gone there to live. The Indian women had a metabolism roughly 17 per cent below that of American women living in the temperate zone.[40] The European women whose metabolism was determined in the temperate zone and later in India reacted in two different ways when they moved into the warm climate: One group showed a decrease of heat production of from 7 to 12 per cent, with no rise in temperature, while the other showed only slight fluctuations in heat production and a rise of temperature of from 0.2 to 0.7 F. It was also shown that Indian women who moved into cold climates had an increase in metabolism of 4.8 per cent. In the case of the European women, Miss Mason said that there was little or no change in the diet and the habits of exercise but there was some loss in weight in the hot climates. She expressed the belief that this loss of weight had no effect on the metabolism, because the metabolism of one European woman on her return to America rose to the standard level of Americans before she regained the weight lost in India. These data indicate that climate and geographic location are of more importance in influencing metabolism than race.[41]

37. Bierring, Einar: The Standard Metabolism of Boys, Copenhagen, Denmark, Levin & Munksgaard, 1931.

38. Martin, C. J.: Thermal Adjustments of Man and Animals to External Conditions, Lancet **2**:219 and 617, 1930.

39. Mason, Eleanor D.: J. Nutrition **8**:695, 1934.

40. Mason, Eleanor D.: Indian J. M. Research **19**:75, 1931.

41. The only exception to the general trend which we have been able to find is the data from Yucatan, which has a subtropical climate. G. D. Williams and F. G. Benedict (Am. J. Physiol. **85**:634, 1928) reported that the metabolism of 4 Americans was measured in Boston and later in a subtropical climate in Yucatan increased from 1 per cent to 9.9 per cent, with an average increase of 6.6 per cent,

(Footnote continued on next page)

Table 15, showing the heat production of girls in different parts of the United States, illustrates the effect of geographic location and climate on American women.[42]

The data concerning the girls reported on here were all treated mathematically in the same manner as that of the Boston series and therefore are comparable so far as it is fair to compare the results of work done by different investigators who attempt to use the same technic. In some instances the series of girls was not sufficiently large to be of statistical importance, but in most instances the number compared favorably with the number reported on by other investigators. It is therefore felt that comparison of the smaller groups throws some

TABLE 15 *(From Talbot, Wilson and Worcester [42]).—Comparison of Heart Production Recorded by Different Observers*

Observer	Age, Years	Number of Cases	Deviation	
			Total Cal. for Height, %	Total Cal. for Weight, %
Benedict and Talbot (Boston)	0-13 incl.	92	0	0
Talbot (new series private school) (Boston)	10-19 incl.	87	0	0
Lucas (San Francisco)	8-18 incl.	207	— 1	— 1
Stark (Wisconsin)	9-16 incl.	52	— 4	— 2
MacLeod (New York)	10-15 incl.	56	— 2	+ 1
Topper (New York)	10-16 incl.	39	+ 4	+ 4
Blunt (Chicago)	8-17 incl.	58	+ 4	+ 3
McKay (Ohio)	13-18 incl.	80	— 8	— 7
McKittrick (Wyoming)	17-26 incl.	100	— 9.5	— 9.9
Stark (university students) (Wisconsin)	17-20 incl.	86	—15	—12*
Remington and Culp (South Carolina)	18-20 incl.	37	—13	—10*
Coons (Oklahoma)	17-22 incl.	99	—17	—16*
Hilt (Florida)	17-20 incl.	40	—16	—14*

* In these four groups the lower limit of age is at the figure (17 years) beyond which we suspect that our standards may be too high.

light on the general problem. The evidence is against there being any racial difference per se in the metabolism of children.

The foregoing data indicate that, whereas basal metabolism is at a different level in different parts of the world, climate and geographic location are the predominating factors responsible for this. The work of Martin on himself during his trip to Australia and that of Eleanor Mason on European women both in America and in India suggest that climate has the most important influence on the level of heat production of adults and that two types of reaction may result from long

and that the values for Maya Indians living in Yucatan averaged + 6.5 per cent higher than the standard figures obtained for adults in temperate zones. This is contrary to the general trend, and we are unable to explain it.

42. Talbot, F. B.; Wilson, E. B., and Worcester, J.: Standards of Basal Metabolism of Girls (New Data) and Their Use in Clinical Practice, J. Pediat. 7:655 (Nov.) 1935.

domicile in tropical climates. Although no children or young adults have been studied in both a temperate and a tropical climate, there is no reason to suppose that they react differently from adults.[43] That they probably do not is indicated in table 15, which gives the difference in the heat production of girls in different parts of the United States, viz, in the North, South, middle states, Far West and East.

These data have an important bearing on the clinical use of standards of metabolism because they indicate that adjustments should be made to the standard used for the community in which the tests are carried out. It is, furthermore, possible that if the metabolism is determined during a prolonged spell of hot weather, special consideration should be given to interpretation of results.

Prof. A. J. Cameron,[44] for whose group of 47 girls the metabolism averaged 6 per cent higher than the average for our group, recognized the fact that there were geographic differences and made an adjustment when he compared his results with the Boothby-Sandiford standard.

It is suggested that if studies on basal metabolism are made in any community other than those mentioned here a group of normal children be studied, the relation of their metabolism to our new standard be determined and the necessary correction be estimated. Before any correction is made the investigator should be sure that he has collected truly basal observations. Average corrections are given for the ages and the cities which we have been able to study and are reported on here.

23. PUBERTY

At or about puberty there is a significant change in the physiology of the body, which is expressed in girls by development of the secondary sexual characteristics and the onset of catamenia (see section 8). It is now known that the intimate interrelationship of the various endocrine glands is such that changes in the activity of one gland may affect the action of others. It is not surprising, therefore, that when a rise was seen in the metabolism curve just before or at the time of the onset of puberty it was concluded that this must be a general rule and must be connected with puberty. Many clinicians have noted an increase in the size of the thyroid gland at this time and subsequently, which may be temporary or may persist for two or three years without causing any symptoms.

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43. Dr. Stark in a personal communication said that a number of the children studied by her lost weight during the summer and that some, according to the parents, had decreased appetites, though they all remained well and the majority were unusually active physically ("playing hard"). In a few cases the basal metabolic rate was noticeably lowered and in some elevated during the hot weather, especially on dark, oppressively humid mornings.

44. Cameron, A. J.: Canad. M. A. J. **15**:1022, 1925.

Du Bois [45] noted in 1916 what he considered a rise in metabolism in boy scouts just before puberty, at the ages of from 12 to 14 years, and later, in 1918, he and his co-workers [46] found that after puberty was established the metabolism of the same boys fell from 25 per cent to 11 per cent above that of adults, a drop of 14 per cent. In 1930 [47] he said: "One of the weakest points in the curve of metabolism published by Du Bois in 1914 to 1915 was a rise in the slope occurring at the ages of 12 to 14, just at the onset of puberty. The number of observations upon which this was based was rather small, and the matter remained somewhat doubtful until fairly numerous confirmations of the last few years."

Among those who have reported a rise in basal metabolism at the onset of puberty are Göttsch,[48] Petényi and Lax,[49] Janet [50] and Topper and Mulier.[17] A rise at that time was also found in MacLeod's girls. Topper studied the largest series, which included 28 girls and 10 boys from 10 to 16 years of age, at intervals of from six months to a year over a period of from one to four years. She found an increase in the basal metabolic rate in the prepubescent period; it reached a maximum around the time that catamenia was established in girls and sexual maturity in boys and then declined. Nylin [36] studied 12 girls at three month intervals and found an increase in the metabolism during pubescence in most of them. Stark's [51] carefully studied children did not show any elevation of metabolism, and in our series there was an elevation of about 100 calories in some instances and none in others. The combined data of all observers indicate that an elevation of the heat production of girls commences roughly at the age of 10 years and reaches its maximum at the establishment of catamenia. The metabolism then falls, and at the age of about 15½ years it is 5 per cent below the average trend. This so-called puberty reaction is not constant in Boston and is entirely absent in Madison, Wis. The irregularity of its appearance may be taken to indicate that puberty per se is not the causative factor.

45. Du Bois, E. F.: Clinical Calorimetry: The Metabolism of Boys Twelve and Thirteen Years Old Compared with the Metabolism of Other Ages, Arch. Int. Med. **17**:887 (June) 1916.

46. Olmstead, W. H.; Barr, D. P., and Du Bois, E. F.: Clinical Calorimetry: Metabolism of Boys Twelve and Fourteen Years Old, Arch. Int. Med. **21**:621 (May) 1918.

47. Du Bois, E. F.: J. Nutrition **3**:337, 1930.

48. Göttsch, O.: Monatschr. f. Kinderh. **32**:22, 1926.

49. Petényi and Lax: Monatschr. f. Kinderh. **36**:381, 1928.

50. Janet, G.: J. méd. franç. **12**:254, 1923.

51. Stark, Marian E.: J. Nutrition **6**:11, 1933; unpublished data.

The pulse rate and its relation to the elevated heat production were next studied. For 12 of Topper's girls, a rise of 100 calories more or less was found at puberty and there was a rise of from 13 to 14 beats in the pulse rate; this represents 7 calories per unit of rise in the pulse beat. Since there is some relation between the pulse rate and heat production, it might seem that the former explains the consistent increase in metabolism seen by Topper. The evidence of other investigators indicates that the pulse rate is not the cause of the elevated metabolism. The pulse rate was not elevated in our subjects in whom there was increased metabolism. There was no elevation in Stark's subjects, and Nylin found that, on the contrary, there was a gradual fall in the pulse rate with increasing age and through the period of pubescence, between 10 and 12 years, a period in which he found the metabolism elevated. The pulse rate, therefore, does not explain the elevation in metabolism.

The groups of girls were composed of different social and racial types. Topper's girls were from the neighborhood of the Mount Sinai Hospital, New York: "All were Jewish, and perhaps therefore more neurotic, more emotional than those met with in New England." [52] Our private school group was composed of girls living in good economic and social surroundings in Boston or the suburbs. Stark's girls were from "university families" at the University of Wisconsin, a "low iodine" state, and were "keen and lively types of children," [53] in accordance with the academic background. Nylin's children were girls living at the State Institution for the Blind at Torntebode, in Stockholm, Sweden.

The influence of the thyroid gland was then considered. It has long been known that before and after puberty the thyroid gland of a girl may be relatively larger than at other periods of life. The intimate relationship between the various endocrine glands made it seem plausible that increased activity of the thyroid might cause an increase in metabolism at puberty. One of us [54] suggested in 1924 that this might have an influence on the heat production. Topper showed that 7 of her girls had an enlarged thyroid gland and normal metabolism until prepubescence, and Talbot [55] has seen numerous children with an easily visible and palpable thyroid and normal metabolism after puberty was established. The lack of relation between the rate of metabolism and the size of the thyroid is seen also in Nylin's case 10,

52. Topper, Anne: Personal communication to the authors.

53. Stark, Marian E.: Personal communication to the authors.

54. Talbot, F. B.: Monatschr. f. Kinderh. **27**:465, 1924.

55. Talbot, F. B.: Unpublished data.

which is recorded in detail. The evidence at hand, therefore, is against the responsibility of increased activity of the thyroid for the elevation in metabolism.

There is a marked increase in growth in height of many persons during prepubescence. With it come changes in the conformation of the body and the character of the person. For our girls and those studied by Nylin a connection was found between the maximum growth in height and the increase in the total heat production. Both these measurements were observed between the ages of 10 and 15 years. If extra growth in height were characteristic of that period and of no other period of life, it might be argued that the elevation in both the growth in height and the metabolism was due to pubescence alone. During infancy, especially the first twelve months, there is another period of rapid growth in height accompanied by rapid increase in and finally elevation of the heat production. The elevation of the heat production, therefore, must be connected with the speed of growth and not with the puberty per se. This will be discussed further in the section on the relation of growth to metabolism.

Although a great deal of work [56] has been done on the period of pubescence, much important evidence is still lacking. The reports of the careful investigations by Nylin give the most complete data. In other reports one factor or another is lacking. The fact that no rise was seen in Stark's carefully studied cases suggests that some unrecorded or uncontrolled factor should be measured before the final answer to the problem is reached.

Our study of the data at hand indicates that there is a rise in metabolism in most girls during pubescence, but it can be absent. After puberty is established, the total heat production is diminished. The evidence is strongly against the theory that the increased activity of the thyroid gland and the elevation in the pulse rate are alone responsible for this rise. There is sufficient evidence to indicate that the extra growth in height is the primary factor with which the elevation of the metabolism is connected.

In our opinion a larger number of girls should be studied and simultaneous records of many kinds should be made. Nylin's method of approach most nearly approximates the ideal kind of research. We

56. Chi Che Wang, Mildred Kaucher and Mary Wing (Metabolism of Adolescent Girls: I. Basal Metabolism and Energy Exchange, Am. J. Dis. Child. **51:** 801 [April] 1936) reported the metabolic rates of 18 girls before puberty and of 16 after puberty, which run very close to our standard. Since the girls came from homes with limited means, in Cincinnati, one might expect their metabolism to run slightly lower, but when it is seen that they averaged —13.4 per cent below the Baldwin-Wood height-weight standard, the explanation is clear.

also believe that because of the number of factors involved, the subject of basal metabolism must be approached by repeated observations on the individual child and not by single observations on many subjects.

24. SPEED OF GROWTH AND THE METABOLISM

While we were assembling our data we received Nylin's [36] important contribution to the study of puberty. His conclusions are worth quoting in detail:

> One of the first expressions of puberty appears to be an accentuated height-growth. The time of its onset and its duration are very varied in different individuals. There appears to be a tangible connection between the onset of the puberty maximum of height-growth and the development of the breasts, both commencing at the same time. The pubic hair, and the axillary hair in particular, do not develop until the later stage of puberty. The onset of menstruation appears to be intimately connected with the cessation of the puberty maximum in height-growth and the ossification process. With the puberty maximum in height-growth the increase in weight is slight. During this maximum the standard metabolism, taken absolutely, increases considerably. . . . During this period the thyroid gland increases in size. The utilization, i. e., the arterio-venous oxygen difference under standard conditions . . . is remarkably constant during growth, from which it follows that the blood-flow is a direct function of standard metabolism. Thus, the minute volume of the heart during the puberty maximum in height-growth, like the standard metabolism, is increased somewhat above that corresponding to growth in height and weight. The pulse rate decreases successively during the whole development and shows no signs of increasing with the onset of puberty. . . . The systolic blood pressure successively increases somewhat during development, there being a slight decrease in the diastolic blood pressure at the same time.

If Professor Wilson's estimation of the comparative value of repeated observations on individual subjects and single observations on many subjects is applied to Nylin's data, the 150 observations on 10 children equal statistically 2,500 observations on different children.

Although our data are of the second type, we found, in the cases in which we had measurements of the speed of growth in height (see section 7), that the metabolism of the child who grew in height faster than the average before puberty was 5 per cent higher than the average.[57] The metabolism of persons who had attained full growth, on the contrary, was 2 per cent below the average. Earlier investigators, Du Bois, Topper and others, thought this elevation of metabolism was

57. This was the situation in case 13, in which growth was rapid for fifteen months and metabolism the highest for any child. At the age of 11 years and 7 months the height was 166.3 cm., the weight 55.9 Kg. and the total calories 2,014, and two months later, at the age of 11 years and 9 months, the height was 167.5 cm., the weight 57.6 Kg. and the total calories 2,140. The maximum height, 174 cm., was reached at the age of 12 years and 9 months; the weight was 64.5 Kg., and the total heat production was 1,618 calories.

connected with and part of the puberty reaction. This theory was discussed in the preceding section. The fact that the greatest growth and the greatest increase in the production of calories start after birth and take place during the first year of life is evidence that growth, principally of height, is the factor with which the speed of metabolism is connected. If one assumes a length at birth of 48 cm., there is during the first year approximately a 45 per cent increase in height. With a weight at birth of 3,000 Gm., there is an increase in weight of 200 per cent. With an initial basal heat production in the new-born of 134 calories, there is an average increase in basal heat production of 360 per cent. At no other time in life are such definite increases seen. The question may be raised as to why height is taken instead of weight as the measure of the speed of growth. The evidence on this point, though scanty in our data, is suggestive and probably confirms Nylin's conclusion. When average curves of growth in height and growth in weight are compared with the curve residual logarithmic calories from weight against age (fig. 3), there is as a general rule a corresponding trend of all these curves, but the increase in height antedates the increase in weight and more nearly corresponds with the curve of calories at all the ages. Furthermore, when growth in height ceases there is a definite tendency for the total heat production to become lower.

We are fully aware of the danger of drawing conclusions from averages in the field of growth and appreciate the many and great variations in the growth of the individual subject. These variations have been emphasized by Davenport.[58] In his study of 100,000 boys, he found the average maximum increase in height at the age of 14½ years. When he superimposed the curves of growth of 3 individual boys on the average curve, the maximum growth of A was at 8½ and 12½ years; of B, with a single maximum, at 15½ years, and of C, at 16½ years. He concluded that "the adolescent spurt is not at all evidence of a monomolecular catalytic reaction, but is an evidence of the method of distribution of the growth spurts. It has really nothing to do with the way a child, or any other young animal, grows."

We have, however, data about the speed with which persons were growing at the time that and after metabolism was recorded, and elevation of metabolism is associated with growth in height that is faster than the average (see section 7). When a child is growing rapidly, at no matter what age, the metabolism is higher than that of a slower-growing child. We present this evidence as an argument that the level of metabolism is affected by the speed of growth. If future work sub-

58. Davenport, in Symposia on Quantitative Biology, Biological Laboratory, Cold Springs Harbor, New York, 1934, vol. 2, p. 203.

stantiates this theory, one explanation is seen for the wide range and scatter above and below the average of the heat production for persons of a given age, height or weight. The relation of growth to metabolism should be studied from many points of view on individual subjects and over long periods of time. A measure of the growth in active protoplasmic tissue of individual subjects is essential to determine if the spurt in the metabolism is due to a greater amount of active tissue or to a change in the activity of the muscles and organs.

25. NORMAL STANDARDS

The term normal standards of metabolism has come into general use among clinicians and technicians in their laboratories and, because it is not understood, has been the source of many errors. What is known as a normal standard in reality is an average standard, made up of the average metabolic rates of a group of normal persons. Most clinicians do not take the trouble to find out how the average standards are computed and, in consequence, have only a vague idea of what they represent and of how wide the spread from the average may be and still include only what is presumably normal. A variation of 10 per cent above and 10 per cent below the average standard has been arbitrarily fixed as the range of normality; but this does not include the rate of all normal persons. Numerous factors must be understood before one attempts to interpret metabolism findings. These will be considered under various headings.

Since this discussion is from the point of view of the clinician who uses the portable apparatus, we shall only mention and shall not discuss the closed chamber, which makes direct or indirect measurements of heat and requires for its operation a highly trained staff such as is used in physiologic laboratories.

1. *Technic of Using the Portable Apparatus.*—Although the technic of operating the portable metabolism apparatus is accurately and carefully described for each apparatus, a careless operator may not take all the precautions necessary to obtain an accurate measurement of the oxygen consumed.

2. *Technic of Handling the Patient.*—Certain technicians are more successful with patients than others because of their tact and experience in handling people, and as a result they obtain basal measurements when others fail. Calmness and confidence on the part of the operator are reflected in the child's attitude. Dr. Stark, in a personal communication, told us of a child whose metabolic rate, obtained satisfactorily on several occasions, showed a marked rise when tested by a new technician. It returned to the usual level when it was determined by another and more experienced operator.

3. *Criterion of Selection of Basal Periods.*—Operators often accept measurements as basal which are in no way representative of quiet periods. The various methods used in selecting basal periods have been reported elsewhere. Too many workers in clinical laboratories assume that when a subject has once had her metabolism measured, the results represent basality. In such instances any figure obtained is acceptable to the operator and the tests of basality are not applied. This is perhaps because basal metabolism tests are performed and interpreted by persons who have not the necessary physiologic training or knowledge. We have had an opportunity to examine many kymographic curves and agree with DuBois in his statement, previously quoted, that there "has been an enormous number of experiments, most of them with poor technic" and therefore worthless.[1]

4. *Variation from Day to Day in the Heat Production of a Normal Person.*—There is a surprising uniformity in the day by day heat production of a given person, but some variation is inevitable (see section 9). It is generally accepted that a 5 per cent variation in the metabolism is not abnormal. The variation may be slightly greater in young children, but it is difficult to determine this point because it is harder to obtain absolutely quiet periods at the early ages. Children of 7 years or younger submit to the test with less calmness than do older children and consequently cannot be tested with the portable apparatus.

5. *Relation of Pulse Rate to Metabolism.*—A relationship between the pulse rate and the heat production has been demonstrated (see sections 7 and 21). The pulse rate during the test should play a part in the decision as to whether the period under consideration is basal. When the pulse rate is much higher than the average for children of the same age, even allowing for individual variations, the data should be looked on with suspicion. The relation of the pulse rate to heat production is discussed in sections 7 and 21.

6. *Effect of Fever on Metabolism.*—Fever increases heat production. The metabolic rates of patients with fever cannot be compared with average standards without taking this fact into account.

7. *Effect of Obesity and Undernutrition.*—This subject is discussed in a separate section, section 27.

8. *Possible Deviation of the Metabolism of a Normal Person from the Average Normal Figure.*—Most published records of metabolism give the percentage deviation of metabolic rates from some standard (see section 20). These figures are valueless as permanent records if the total heat production, from which is calculated the percentage variation, is not recorded, because standards may change. All records

of metabolism should have the fundamental data, total calories, recorded. The age, height, weight, onset of puberty, clinical status, pulse and temperature should also be recorded as part of any record to make it of the greatest value. Since the standards give only the average figure for heat production and give no definite limit above and below this average to which the normal may be extended, it seems wise to show the distribution for one group of normal persons, which is roughly characteristic of all groups.

Figure 10 illustrates the range of the metabolism of 465 girls of normal body build aged from 10 to 18 years. Practically speaking, this chart means that if the metabolism of a normal girl between 8 and 18 years of age is compared with the average standard for girls of her weight, the chances are 81 per cent that it will fall within 15 per cent of the average. Although the rates of four fifths of the normal girls fall within ±15 per cent of the standard average, it is possible that the figure is even smaller for groups of older persons. It may be smaller for some groups of persons and larger for others. It seems reasonable to assume that the older the persons and the greater the understanding and cooperation they give, the smaller will be the range within which the normal measurements will fall. The plus side opens up the question of absolute basality. It is obvious that some operators are more successful in obtaining basal measurements than others and that some are particularly successful with children. We believe that the claim made by Kestner and Knipping [59] that they seldom find a deviation of more than 5 per cent above the calculated standard which bears their name, but which is a modified projection of the Harris-Benedict multiple prediction formula, is not justified and that, in the words of DuBois (loc. cit.), "It is almost too good to be true" (see section 26, part 3). When their standard is applied to the group of 87 Boston private school girls from 10 to 18 years of age, one third of the measurements fall outside ±10.7 per cent.

When standards of metabolism were first published for children, Talbot [60] suggested that a variation of ±10 per cent includes the rate of most normal children and that greater deviations are probably abnormal. Experience in subsequent years of clinical practice made it desirable to extend the normal figure to a variation of ±15 per cent from the average. When a metabolic rate is 16 per cent or more below the normal by the average weight standard (table 3) it is probably clinically

59. Kestner, O., and Knipping, H. W.: Die Ernährung des Menschen, Berlin, Julius Springer, 1926.

60. Talbot, F. B.: Standards of Basal Metabolism in Infants and Children, Am. J. Dis. Child. **21**:519 (June) 1921.

significant.[42] A statistical study of normal and pathologic conditions substantiates this conclusion. Metabolic rates of more than 15 per cent above the average standard have a further source of error in that there is no certainty that they represent basal figures until several tests have been performed on subsequent days. Other factors which may increase the basal metabolism of normal children are discussed later.

9. *Choice of Metabolism Standards.*—It is unfortunate that Rubner and Richet promulgated the doctrine that metabolism is proportional to surface area among warm-blooded animals because this doctrine suggested that the relationship between surface area and heat production is causal. There are clinicians today, who have not followed the developments of science in the literature, who still hold this to be true. One is surprised that this theory had so much support and played such a large part in the discussion of the subject when one looks into the literature and finds how few actual measurements were made of the surface area of the body. The body surface formulas for children until recently were based in fewer than 10 cases on measurements that could be considered normal; in all other cases the subject was pathologic, underweight or a cadaver.

In recent years the majority of scientists have accepted as most plausible the theory that the basal heat production is dependent on the amount of active protoplasmic mass, and there are few proponents of the theory that the surface area of the body determines the amount of heat produced. On the other hand, emphasis has been laid on the fact that a mathematical relationship can be found between basal heat production and the surface area of the body calculated from height and weight or by formula from various linear measurements of the body. A mathematical relationship can be found for any large group of data; that is the job of the mathematician. Typical examples of body surface formulas are the DuBois height-weight and the DuBois linear formula. We applied these two formulas to a group of normal children, a group of children with malnutrition and a group of obese children. The results agreed closely for the underweight and the normal groups but did not agree well for the 54 obese children. For this group there was an average difference of 8 per cent and a maximum difference of 22 per cent in the area of body surface as estimated by the two formulas. Since in clinical practice the diagnosis and treatment are most important in the case of the abnormal child, the possibility of error in estimating body surface increases the probability of error in the final figure obtained. If other possible errors due to the use of height and age coefficients in the formula accumulate, the final result may be entirely inconsistent with clinical experience and the facts of the case.

The various formulas which have been devised, and there are many of them for predicting both the surface area of the body and the heat production, merely express a close mathematical relationship between groups of data. Any formula fits the data from which it is derived, but there is no telling how it will fit other data; nor is there any guarantee that its application will separate pathologic from normal conditions. The same data can be used by different mathematicians, and formulas derived from them can be expressed in different ways, and the results may all be mathematically correct. All the many prediction formulas published are concerned with data obtained from "normal" persons, but the range of physical normality is not closely defined. Although persons with certain types of pathologic conditions are of normal weight for their height, the measurements of many others fall outside the normal limits, and there is no reason why formulas constructed for persons of normal physical development are necessarily correct for abnormally developed persons. This side of the question has received scant consideration, and in our opinion the final word will not be said and permanent standards will not be developed for clinical use until the widest ranges of normality are taken into consideration. This we have endeavored to do.

26. COMPARISON OF GROUPS AND STANDARDS

1. *Repeated Versus Single Observations.*—Clinical experience with various standards applied to children over the last ten years led to the conclusion that fewer mistakes in diagnosis are made when the metabolism of children is compared with the average total metabolism of persons of the same weight and sex. This conclusion is modified under certain conditions. The material available for study, though more inclusive than that which had previously been the basis of reports, left much to be desired. Prof. E. B. Wilson [61] showed the value of repeated observations on the same child over a period of years in contrast with that of many observations on different persons of different ages. He estimated that measurements made on each of 10 children once a year for sixteen years, a total of 160 observations, would give as much knowledge about the way children grow as, or more than, 1 observation on each of 2,500 children. Nylin made repeated observations on the same children for four years and Topper for shorter periods, and Stark has such a series in process. Similar studies on growth are being conducted under the direction of Dr. Harold Stuart at the Harvard School of Public Health and by Dr. Alfred Washburn

61. Wilson, E. B.: Heights and Weights of Two Hundred and Seventy-Five Public School Girls for Consecutive Ages of 7 to 16 Years Inclusive, Proc. Nat. Acad. Sc. **21**:633, 1935.

at Denver. As Davenport [58] pointed out, when the growth of one person is compared with the growth average of many persons, it may not conform at all even though it is perfectly normal.

One of the purposes of our investigation was to fill in a relatively blank space, that is, to supply data for the age range from 12 to 20 years, to give a basis for a single standard extending from birth to the adult age. If the general principles presented here stand the test of future inquiry, the burden of proof is placed on those working with adults to prove why they are not equally applicable to adults.

2. *The Aub-Du Bois and Harris-Benedict Predictions.*—We made a study of various types of data and compared them with the predictions obtained from our average-weight standard, the Aub-Du Bois standard and the Harris-Benedict standard. The subjects were separated into a young group and an older group, each of which was subdivided into two groups; one of these contained only the girls whose weight fell within — 10 and + 20 per cent of the Baldwin-Wood weight for height standard, and the other included presumably normal girls who were thinner or fatter than this arbitrary standard. The accuracy of the formulas as applied to group 1, 130 normal college girls of 16 years and older with normal weight for height, is compared in the following tabulation:

Standard	Average, Percentage	Standard Deviation, Percentage
Total calories for weight.....	— 15.6	± 8.0
Aub-Du Bois	— 11.0	± 7.7
Harris-Benedict	— 9.9	± 7.5

Although the standard deviation found for this group is in favor of the Harris-Benedict formula and against the weight standard, the differences are so slight that they are not statistically significant. In other words, one may expect these standards to be equally useful, leaving other things out of consideration, in clinical practice.

When the same group is enlarged to include the presumably normal underweight and overweight girls, 201 girls in all, the standard deviations are as follows:

Standard	Average, Percentage	Standard Deviation, Percentage
Total calories for weight.....	— 15.3	± 7.8
Aub-Du Bois	— 10.7	± 7.7
Harris-Benedict	— 9.8	± 7.8

Here the Aub-Du Bois formula shows up a little better than the other two, but the prediction values of all three are identical.

The younger group, of 134 children, whose measurements can be compared with the Aub-Du Bois standard, were from 14 to 18 years and older.

Standard	Average, Percentage	Standard Deviation, Percentage
Total calories for weight.....	— 5.0	± 10.7
Aub-Du Bois	—11.0	± 11.8

When this group is enlarged to 194 girls and includes the normal underweight and overweight girls, the following relations are seen:

Standard	Average, Percentage	Standard Deviation, Percentage
Total calories for weight.....	— 4.4	± 11.0
Aub-Du Bois	—10.9	± 12.1

These comparisons show insignificant variations in the standard deviations when the three standards are applied to children of 14 years or more.

3. *The Kestner-Knipping Standard.*—The Aub-Du Bois and the Harris-Benedict standards were not constructed for use with younger children. The Kestner-Knipping standard, which was said to be very accurate, was based on the work of Schadow [62] and was constructed on the principles of the Harris-Benedict prediction tables; 75 per cent of Schadow's measurements lie between — 4 per cent and + 8 per cent of this standard.

For a group of 58 private school girls of from 14 to 18 years, the standard deviations are as follows:

Standard	Standard Deviation, Percentage
Total calories for weight.....	± 5.1
Aub-Du Bois	± 6.5
Kestner-Knipping	± 9.8

For an enlarged group, 87 girls of from 10 to 18 years, they are:

Standard	Standard Deviation, Percentage
Total calories for weight.....	± 11.7
Total calories for weight corrected for age.....	± 10.5
Kestner-Knipping	± 10.7

For the smaller group the weight standard shows a significant advantage over the Kestner-Knipping standard but not over the Aub-Du Bois standard. The metabolic rates of two thirds of the children fall within 5.1 per cent of the weight standard and within 9.8 per cent of the

62. Schadow, H.: Ztschr. f. Kinderh. **34**:145, 1926.

Kestner-Knipping standard. For the larger group, the metabolic rates of only two thirds of the girls fall within ±10.7 per cent of the Kestner-Knipping standard, which disproves the claim of those authors to a ±5 per cent accuracy for their standard.

For 53 girls under 14 and over 1 year (Benedict and Talbot series), the standard deviation from the standard of total calories for weight was ±7.5 per cent and from the Kestner-Knipping formula ±12.4 per cent, a significant difference and evidence of the greater accuracy of the weight standard for this particular group of children.

Since the mathematical differences in the three standards are not significant for older girls, one may question why one standard should be recommended above others. The main arguments for using total calories for weight are (1) that by so doing there can be no accumulation of errors; (2) that fewer errors in diagnosis result from its use, at least in clinical practice with children, and (3) that it is the most accurate for younger children. It is obviously advantageous to be able to apply one standard to all age groups.

27. MALNUTRITION AND OBESITY

1. *Moderately Underweight and Overweight Girls.*—Various groups were studied to enlarge the range beyond the arbitrary limits of normal physical development, viz., from —10 to +20 per cent of the weight for height standard as given in the Baldwin-Wood height-weight table. The extension of these limits to include children with mild malnutrition or mild obesity presumably created a widened group of persons who were normal at least from the metabolic point of view. Although there is no cleancut line between pathologic and normal malnutrition and obesity, it was assumed that the milder stages of these two conditions were examples of the extremes of normality and that the extreme grades of malnutrition and probably of obesity also were metabolically abnormal. Neither of these conditions studied alone gives a clear picture of their place in the general picture, but it was felt that if the various stages of both could be studied general trends could be established and from these generalizations could perhaps be made. The various comparisons (section 2) indicate that the use of the new standard, total calories for weight, is as accurate as, if not more accurate than, other standards, even when tested with the limits of normality widened.

Although Means [63] found the metabolism of obese adult women normal when calculated according to the surface area formula, the findings for children have been variable and the surface area standards unsatisfactory. The error in estimating the surface area of obese chil-

63. Means, J. H.: J. M. Research **32**:121, 1915.

dren may explain some of the results obtained, but some other factor is probably the determining element. Langmead and Calvert [64] made a study of 8 boys and 4 girls in 1924, and Topper and Mulier [65] of 78 subjects in 1929. In addition, we have studied 35 new cases, and reports of numerous other cases of obesity of varying degrees may be found in the literature.

The data on malnutrition were obtained with more difficulty because this condition is so often a complication of other diseases which may affect the metabolism. Schick and Cohen [66] made a study of convalescent children in 1925, reporting low metabolism after the disappearance of fever. Fleming [67] in 1921 and Talbot [68] in 1921 each reported on the metabolism of underweight infants. Levine and Wilson [69] reported a similar but more complete study in 1928. For older children there are the reports of Wang and others [70] published in 1926 and of Topper and Mulier [71] published in 1929. In addition, numerous reports of cases are scattered through the literature, and we have added new unreported cases of our own.

A study was made of varying grades of malnutrition and obesity, and the measurements were compared with our new normal average standards, with the following results.

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64. Langmead, F. S., and Calvert, E. G. B.: Obesity in Children, Lancet **2:** 1111 (Nov. 29) 1924.

65. Topper, A., and Mulier, H.: Basal Metabolism of Children of Abnormal Body Weight: Basal Metabolism of Overweight Children, J. A. M. A. **92:**1903 (June 8) 1929.

66. Schick, B., and Cohen, P.: Lowered Basal Metabolism, in Postinfectious Stages and in Diseases Characterized by Slow Pulse Rate: Preliminary Report, Am. J. Dis. Child. **30:**291 (Sept.) 1925.

67. Fleming, G. B.: Investigation into Metabolism in Infantile Atrophy, with Special Reference to the Respiratory Exchange, Quart. J. Med. **14:**171 (Jan.) 1921.

68. Talbot, F. B.: Severe Infantile Malnutrition: Energy Metabolism with Report of a New Series of Cases, Am. J. Dis. Child. **22:**358 (Oct.) 1921.

69. Levine, S. Z.; Wilson, J. R., and Gottschall, G.: The Respiratory Metabolism in Infancy and in Childhood: VIII. The Respiratory Exchange in Marasmus: Basal Metabolism, Am. J. Dis. Child. **35:**615 (April) 1928; IX. The Respiratory Exchange in Marasmus: Carbohydrate Metabolism of Normal and of Marasmic Infants With and Without the Administration of Insulin, ibid. **36:**470 (Sept.) 1928; X. The Respiratory Exchange in Marasmus: Specific Dynamic Action of Food in Normal and in Marasmic Infants, ibid. **36:**740 (Oct.) 1928.

70. Wang, Chi Che; Frank, Margaret; Hays, Bertha B., and Kern, Ruth: Metabolism of Undernourished Children: I. Gain in Weight, Am. J. Dis. Child. **32:**63 (July) 1926; II. Basal Metabolism, ibid. **32:**350 (Sept.) 1926; III. Urinary Nitrogen with Special Reference to Creatine, ibid. **32:**360 (Sept.) 1926.

71. Topper, A., and Mulier, H.: Basal Metabolism in Children of Abnormal Body Weight: In Underweight Children, Am. J. Dis. Child. **38:**299 (Aug.) 1929.

Group I was made up of moderately underweight and moderately overweight children from 8 to 18 years of age. The obese children were between 20 and 33 per cent overweight and the malnourished ones between 10 and 20 per cent underweight. Their measurements were collected by Blunt, MacLeod, Stark, Lucas and Talbot.[72]

Number of Cases	Condition of Subject	Total Calories for Weight, Percentage	Total Calories for Height, Percentage
189	Underweight	+3.8	—7.2
465	Normal	+0.1	—0.7
53	Overweight	—4.4	+8.7

There is a significant deviation from the normal by the weight standard and a definite difference by the height standard.

The second group represents older girls, from 16 to 35 years of age, reported on by Coons, Tilt, Remington, Culp and Stark (students in the University of Wisconsin). The malnourished girls were more than 10 per cent and most of them less than 20 per cent underweight. The obese girls were 20 per cent or more over the standard weight for height; in most of the cases the weight fell between 20 and 33 per cent above the standard.

Number of Cases	Condition of Subject	Total Calories for Weight, Percentage	Total Calories for Height, Percentage	Aub-DuBois Standard, Percentage
91	Underweight (from 10 to 20 per cent)....	—13.9	—22.5	—14
262	Normal	—14.0	—15.6	—11
57	Obese (from 20 to 35 per cent overweight)	—15.1	— 3.4	— 9

If, instead of using our standards, we compared the measurements of the underweight and the overweight girls with their own normal measurements, indicated by zero, results similar to those given for group I were seen; they are illustrated in the following tabulation:

Number of Girls		Total Calories for Weight, Percentage	Total Calories for Height, Percentage	Aub-DuBois Standard, Percentage
91	Underweight	+0.1	— 6.0	—3
262	Normal	0.0	0.0	0
57	Obese	—1.1	+12.2	+2

2. *Very Obese Girls.*—A group of very obese children (new data, Talbot; see section 19) were next compared to the standards.

	Age, Years	Total Calories for Weight, Percentage	Range, Percentage	Total Calories for Height, Percentage	Range, Percentage
12 obese children* (from +33 to +80 per cent weight for height)	5 to 15	+1.1	—9.7 to +10.8	+25.7	+3.4 to +46
23 children with pituitary obesity (from +33 to +100 per cent weight for height).....	1 to 14	+2.1	—32 to +19†	+28.6	—10 to +68

* At the Massachusetts General Hospital.
† One child, not included here, had the extraordinary value of +145 per cent.

72. The measurements for Lucas and Talbot are from unpublished data.

3. *Comparison of Varying Grades of Obesity.*—When all the grades of obesity are compared with one another (see section 18), the calculations appear as follows:

	Weight for Height, Percentage	Total Calories for Weight, Percentage	Total Calories for Height, Percentage
Mildly obese (young group)	+20 to + 30	—4.4	+ 8.7
Mildly obese (older group)	+20 to + 33	—1.1	+12.2
Very obese	+33 to + 80	+1.1	+22.7
Obese, with signs of pituitary disease	+30 to +100	+2.1	+28.6

There is little change in the average figures when calories are referred to weight and an increasing difference with increasing obesity for height. This seems to indicate that there is an increase in active heat-producing tissue with increasing weight. The range of variation in the metabolism of the markedly obese (excepting the figure of +145 per cent) is much greater for height than for weight. It is 20.5 per cent for weight and 42.2 per cent for height for the first group and 51 per cent and 78 per cent, respectively, for the group with pituitary disorder. The weight standard therefore seems to give a more accurate picture than the height standard. The possibility of some endocrine disturbance in the obese must also be borne in mind. Since there is as yet no accurate method of diagnosing such conditions, it is impossible to discriminate except roughly in these cases.

Statistically there is no essential difference in heat production in the various grades of obesity when the heat production is compared to weight, but there is a marked difference when it is compared to height. This makes it obvious that unless some compensation is made for the excess weight, any standard which includes height in its prediction formula is open to definite possible error.

From the clinical point of view, the problem is by no means solved. Satisfactory results are seen for the group of 12 obese children whose range of metabolism is within the variation of ±15 per cent from the average standard for weight. This does not hold for the height standard for either group, nor does it apply to the weight standard for the group with pituitary disorder. The extremes are far outside the ±15 per cent variation.

One must resort to theory and clinical experience to explain such divergence. It is possible that a small proportion of these girls actually had an endocrine deficit which caused a lowering of the metabolism. Yet in clinical practice the proportion of obese children who are able to take therapeutic doses of thyroid approaching those required by cretins is relatively rare. In our experience, thyroid therapy has usually caused toxic symptoms in obese children and has rarely been beneficial. There is no good evidence that thyroid deficiency is present in obese children unless its clinical signs and symptoms accompany the obesity.

The average findings for a group, although indicating a trend, cannot be expected to represent the characteristics of a given individual. This fact is familiar to the clinician, and when a patient or several patients fail to conform to the general trend he is not surprised, because consideration of accessory or unknown factors is a part of his daily experience. This has been commented on by Davenport [58] in his discussion on growth, which was considered in another section.

To illustrate the many possible varieties of obesity, a theoretical picture of what might happen will be described. If a child gains a great deal of weight in a short period of time and at the same time is lazy and exercises little, one expects a great proportion of that weight to be fat or inactive tissue. Granting that active tissue, such as muscle, which is the source of the heat produced, does not increase with the increase in weight and that there is no increase in height, then the metabolism should be minus for the weight and normal for the height. The presumption is that this stage of obesity is temporary and that it was not represented in any of our cases.

Suppose, however, that the onset of the obesity is slow or the child takes the normal amount of muscular exercise; or suppose a normal person has a load of 20 or 30 pounds strapped to him day and night in place of the fat. To carry the extra load around there must be an increase in the muscle tissue. Something similar to this has been observed in athletes and in men who do hard manual labor. The increase in muscle of the obese can be recognized by any clinician. Its effect on the metabolism depends on the relation of the active to the inactive tissue when the weight standard is consulted. This may explain the wide range of results for the very obese children studied by us. Since height is more or less stationary, one expects a higher metabolism for the height with increasing weight. This elevation was seen in our cases. One therefore assumes that most of our obese children had been fat for a long time. It is not difficult to imagine many varieties of persons and many combinations of active and inactive tissue.

Further study of this complicated subject is needed, with some measure of the active tissue and other factors, before the picture can be clarified. This theoretical picture, however, is not inconsistent with the findings previously reported.

4. *Malnutrition.*—A study of mildly underweight children shows that they tend to have normal or slightly plus metabolism for their weight and lower than normal metabolism for their height. No clean-cut data are available to us except for infants on whom the effect of marked and prolonged undernutrition could be studied, but many experiments have shown that the more pronounced the loss of weight the

fewer the calories produced.[73] Undernutrition is associated with diminished heat production for the height and slightly elevated heat production for the weight.

The findings for infants differ from those for children. The only explanations which suggest themselves for this are that the physiology of infants is less stabilized than that of children, the increment of growth is greater in infancy than at any other time of life and any loss of weight is proportionally greater than an equal amount later in life. Growth in height is often stopped temporarily or even for months in undernourished infants.

Talbot[68] confirmed and supplemented the findings of Fleming[67] that when infants commence to lose weight the loss in body substance is mainly fat or inactive body tissue. This is evidenced by higher heat production for the weight and normal heat production for the height. In more pronounced malnutrition, seen in children who are the greatest percentage under the expected weight for their height and age, there is evidence of diminished heat production, which is believed to indicate loss of active protoplasmic tissue. Further studies, with a measurement of active protoplasmic tissue, such as the amount of creatinine excretion, as suggested by N. B. Talbot,[24] will probably settle this problem. Theoretically, the sequence of events which may take place over a period of weeks or months in an infant is compressed into a short period of days when there is complete fasting. An example of this during childhood may be found in an article by Talbot and others[74] published in 1925.

Levine and Marples[75] made a biometric study of the basal metabolism of normal infants. Their group included 4 undernourished infants, whose total metabolism when compared to the original Benedict-Talbot standards suggests that they may have had severe malnutrition. The work of Topper and Mulier[71] in various types of malnutrition included studies of 35 girls, and their data are the best available on older children. Their subjects varied in weight between — 10 per cent to — 33 per cent from the normal. In general, their trend of metabolism was similar to that seen in infants. The total calories for weight did not deviate far on either side from the standard. The same was true of the total calories for height until the loss in weight was more than 20 per cent, and when it was 25 per cent there was a definite decrease in the

73. Benedict, F. G.: A Study of Prolonged Fasting, Publication 203, Carnegie Institution of Washington, 1915.

74. Talbot, F. B.; Dalrymple, A. J., and Henry, M. F.: Skin Temperature and Basal Metabolism During Fasting, Am. J. Dis. Child. **30**:491 (Oct.) 1925.

75. Levine, S. Z., and Marples, Eleanor: The Respiratory Metabolism in Infancy and in Childhood: XII. A Biometric Study of the Basal Metabolism in Normal Infants, Am. J. Dis. Child. **41**:1332 (June) 1931.

heat production for height, which fell as low as —30 per cent. This indicates that when 25 per cent or more of the body weight is lost there is a definite difference in the character of the metabolism. It is interesting to note that there is also a change in the trend of heat production in the extremely obese. Both extreme malnutrition and obesity should be subjected to intensive study to complete the picture.

Any subject who comes to the clinician to have his metabolism interpreted may be to a great or small degree underweight, and it is important for the clinician to know how the various stages of malnutrition may affect the metabolism of the normal person, in order that he may make a correction for it when the subject is pathologic.

Although there are not yet enough studies to settle all phases of the subject, the theoretical probability is somewhat as follows: During the process of losing weight, the storehouses of fat supply the larger proportion of the needed energy to conserve the more useful and important muscular and other active protoplasmic tissue. At some stage the change in the proportion of active heat-producing tissue is detected. As more body weight is lost, the reserves become depleted, so that it may be necessary for the body to use up proteins, and it is not unreasonable to suppose that when finally the body metabolism cannot keep up the normal temperature unaided the heat-producing components of the body are unable to produce as much heat as the same amount of healthy tissue. On the other hand, the possibility still exists that less active tissue is lost than has been previously assumed and that the tissue itself acts less efficiently and produces less heat. Coincidental measurements of creatinine and heat production during the progress of the disease ought to throw much light on the subject.

Obesity and malnutrition have not received the attention they deserve in clinical studies of metabolism. The standards commonly in use do not take these conditions into account. It is obvious that they will affect any standard that includes height in the formula. Furthermore, the use of standards, including height, may distort the figures for persons in some types of abnormal conditions so that the real picture is obscured and a wrong clinical interpretation is made.

28. PATHOLOGIC CONDITIONS

1. *Cretinism—Hypothyroidism.*—(For pathologic conditions, see also section 19.) The metabolism of a group of 24 untreated cretin girls was compared to the new standard (table 3). These 24 subjects were especially useful as examples of persons with abnormal body proportions and known pathology. They were proved to have a heat production lower than normal, and their clinical status, as well as their metabolism, reacted characteristically on the administration of thyroid.

The metabolism of this group (group IV) when compared with that of normal children of the same weight and height shows the following deviations:

	Total Calories for Weight, Percentage	Range, Percentage	Total Calories for Height, Percentage	Range, Percentage
24 cretin girls (enlarged series).....	—30.7	—52 to —10	—24.5	—48 to + 11

Clinically, all these cretins were known to have hypothyroidism; all improved mentally and physically after thyroid therapy was given. In all the cases measured, the rate of metabolism increased with treatment.

The fact that the average departure of the metabolism from the weight standard was somewhat greater than that from the height standard (an average difference of 5.5 per cent) suggested that the weight standard gives the more accurate picture of the clinical status of these children. On the other hand, if the extremes of range of the metabolism of the individual children are studied, it will be seen that the deviation from the standard total calories for height of + 11 per cent is positive clinical evidence against hypothyroidism in a case in which the condition is known to be hypothyroidism by clinical and therapeutic tests. A plus metabolism for the height was found in 2 instances. A deviation of — 10 per cent from the weight standard, though within normal limits, is less confusing clinically. If it is admitted that cretinism is a definite condition which is unmistakable and that its main characteristic is failure of the thyroid gland to function, then with a deficit or absence of thyroxine the metabolism must be low. Clinical evidence of such low metabolism is seen in subnormal temperature, cold surface of the skin and sluggishness in all actions.

If a standard based on weight gives a metabolic rate which is always subnormal and a standard based on height gives a metabolic rate which is higher than the average in some cases, then the standard based on weight gives results which are more consistent with clinical findings than that based on height. This is presented as an important piece of clinical evidence in favor of the conclusion that the standard "total calories for the weight" gives the most accurate picture of the clinical status of a person with this type of pathologic condition. It also suggests that the use of height in formulas of prediction is responsible for some of the results which do not agree with clinical experience.

Clinical experience also suggests that the speed of metabolism of a unit of active protoplasmic tissue may be lower in these cases. There is a quick response of the metabolism to thyroid therapy even before there is an opportunity for the amount of active tissue to increase. A study of the effect of thyroid, the creatinine excretion and the heat production will help to elucidate this point.

2. *Hyperthyroidism.*—A small group of girls with definite exophthalmic goiter was studied. Eleven measurements were made on 10 girls aged from 5 to 12 years who averaged 8 per cent underweight for their height.

	Total Calories for Weight, Percentage	Range, Percentage	Total Calories for Height, Percentage	Range, Percentage
Girls with exophthalmic goiter...	+ 25	+ 6 to + 59	+ 21	+ 4 to + 48

In these data, like those obtained with cretins, the weight standard expresses the clinical picture better than the height standard, since it predicts a high metabolism. In a subject observed for three years a return of the heat production to the level of the standard average heat production for the weight was accompanied by good health. Each time the metabolism became elevated much above + 15 per cent symptoms of nervousness appeared.

29. SELECTION OF STANDARDS OF BASAL METABOLISM FOR CHILDREN

As has been noted before, many standards have been devised to predict the metabolism of children. All these standards are founded on data collected from groups of normal persons. It is an easy matter for a mathematician to construct a formula which will accurately fit any group of figures collected, but there is no assurance that the formula will fit other normal groups. As a matter of fact, all formulas now in use, whether they relate to body surface or height-weight or any other measurement, will fit fairly accurately any given group of data on normal persons. We have shown that corrections have to be made for different geographic locations, but with these corrections the foregoing statement holds.

When these various formulas are applied to a given group of normal children, it is found that whatever mathematical differences there are in the fits are insignificant, and it seems to us that the voluminous discussion of the pros and cons of one formula as compared to another are academic and have no bearing on clinical practice. We believe that the formulas merely express an accidental relationship and not a physiologic law. Mathematically, we found that the "total calories for the weight" gave the closest fit of any method used for predicting calories for the groups of girls studied by us, and there is a certain amount of evidence that the same is true for boys. We cannot, therefore, see what advantage there is in multiplying with other factors or in estimating body surface, because any error in the original measurements may be intensified by so doing.

We make an exception to this generalization in respect to age. We have found that an age correction of the weight prediction improves the correlation.

Since nearly all standards predict the metabolism of normal persons equally well, the selection of a standard for practical clinical use should depend on which standard gives the truest clinical picture for persons with abnormal and pathologic conditions. That problem has bothered many practical clinicians. We have attempted to apply this test to persons with the clinical conditions in which it will be most helpful and have presented tentative evidence that the "total calories for the weight" gives the prediction desired.

SUMMARY

Before generalizing, we must draw attention to certain factors which we believe modify the metabolism. They include geographic situation, which cannot be separated from climate. Knowledge to date indicates that the level of the metabolism is different in different latitudes. If the standards presented here are generally accepted, a correction should be made for the locality in which the investigator works. We do not believe that race affects the metabolism.

There is a very definite relation between body weight and heat production. Mathematically, the correlation of heat production is closer with body weight than with any other factor studied by us. It has been shown by Brody, Procter and Ashworth [76] that there is a similar close correlation between weight and the creatinine output not only in man but also in warm-blooded animals of all sizes. Finally, attention has been drawn to the correlation between the creatinine output and the basal heat production. Since the creatinine output is accepted as a measure of active protoplasmic tissue, it may be said with assurance that the active protoplasmic tissue of the body is the principal factor of importance connected with heat production.

Many accessory factors may modify the amount of heat produced even under basal conditions. They are so interrelated that it is difficult to separate one effect from another. Age, for example, seems to have some effect, and different eras of life are physiologically unlike. After birth there is tremendous proportionate growth in both height and weight; it reappears with a spurt at or about puberty, accompanied by other changes. After this growth gradually diminishes and finally disappears entirely, when full growth is attained, the person enters adult life. This may be earlier in some persons and later in others. Growth usually terminates at about 20 years. For the next two or three decades

76. Brody, S.; Procter, R. C., and Ashworth, U. S.: Growth and Development with Special Reference to Domestic Animals, Research Bulletin 220, Agricultural Experiment Station, University of Missouri College of Agriculture, 1934.

there are few changes in the normal physiologic processes. Then comes the slow degeneration of old age, the onset of which varies with different persons.

The main difference between the adult and the child is that the former is a finished product which remains in the status quo and the latter is continuously changing. We have presented here considerable evidence to the effect that there is a relation between the speed of growth and surplus metabolism. This should be considered every time metabolism is interpreted by the clinician. Our evidence indicates that the elevation in metabolism seen just before puberty is not due to puberty per se but to the speed of growth.

The standards presented here are, like all other standards, averages. If they are used, the coefficient of variability should always be kept in mind. They have the advantage of being direct measurements which require no formulas and are thus open to less possibility of accumulation of errors. They include new data which help to fill in the blank spaces of from 12 to 20 years and thus connect young childhood with adult life.

THE BASAL METABOLISM OF NORMAL BOYS AND GIRLS FROM TWO TO TWELVE YEARS OLD, INCLUSIVE

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"An ideal study of the metabolism of children from birth to puberty would be the continuous measurement of the same child at frequent intervals throughout this period of life." This statement of Benedict and Talbot [1] would be none the less apt if applied to all the many physiologic activities and not limited to energy metabolism. The actual accomplishment of a correlated, longitudinal study of this type requires much equipment, a large research staff and adequate financial support for many years. To provide an organization and resources for such a study on the normal child from birth through adolescence has been the aim and vision of the Child Research Council.

The plan of the council is to maintain a study of 100 normal children, more or less evenly divided between girls and boys, on whom observations are begun not later than one month after birth. The members of the group are boys and girls from private homes in Denver and its vicinity. Their inclusion in the group depends solely on the willingness of the parents to cooperate; no characteristic of the child is used as a criterion of selection. In addition, a special series of about 50 children is being studied. Some of these are infants who have been observed from birth and will be transferred to the birth series as vacancies occur; others are older children on whom observations were begun too late for them to qualify for the birth series. All classes except the lowest stratum of society from an economic standpoint are represented by the families of the children.

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1. Benedict, F. G., and Talbot, F. B.: Metabolism and Growth from Birth to Puberty, Publication 302, Carnegie Institution of Washington, 1921.

The routine observations made on each child at frequent intervals include a complete physical examination, roentgenographic examination of the chest, sinuses, gastro-intestinal tract, spine and long bones, electrocardiographic examination, social studies, psychometric tests and psychiatric studies, the making of blood pressure tracings, orthodontic studies, including the taking of intra-oral, extra-oral and cephalometric roentgenograms, profile and full face photographs and casts of the dental arches, clinical laboratory tests, anthropometric measurements and determination of the basal metabolism.

The studies on basal metabolism were begun in 1932 as part of the general program of the Child Research Council. At that time the ages between birth and 10 years were well represented by the children already under observation. During the past four years data sufficient for interpretation have been secured for the age groups from 2 to 12 years, inclusive, and are presented herewith as a report of progress.

REVIEW OF THE LITERATURE

Since many excellent reviews of the subject of basal metabolism are available, it is sufficient to include here a summary only of the material which pertains to children between the ages of 2 and 12 years, inclusive. It seems advisable to consider in detail the work in which the rigid experimental conditions now deemed necessary for the accurate determination of basal metabolism were maintained and to pass more lightly over that in which, for various reasons, the modern ideas of approved technic were not followed.

Much of the early work falls into the latter class. The data reported by many of the pioneers in the field are not comparable to those obtained recently by a more exacting procedure, since the experiments were not planned primarily for the study of basal metabolism. Before 1910, studies on energy metabolism were carried out, for the most part, with a large respiration chamber type of apparatus, and conditions of fasting and of muscular repose on the part of the subject were not established. However, the results of these early researches played an important part in the development of the subject of nutrition, and many of the general conclusions drawn from them still hold.

The first reports of investigations on children were those of Andral and Gavarret [2] and Scharling,[3] which were published in 1843. From their results with children and adults, these authors concluded inde-

2. Andral, Gabriel, and Gavarret, Jules: Recherches sur la quantité d'acide carbonique exhalé par le poumon dans l'espèce humaine, Ann. de chim. et phys. **8**:129, 1843.

3. Scharling, E. A.: Recherches sur la quantité d'acide carbonique expiré par l'homme dans les vingt-quatre heures, Ann. de chim. et phys. **8**:478, 1843.

pendently that boys burn more carbon than girls and that children produce proportionately more carbon dioxide than adults. Forster, in 1882,[4] and Speck, in 1892,[5] presented the same conclusions. A few years later, in 1895, Sondén and Tigerstedt,[6] by their studies of the carbon dioxde production of a large number of subjects, added a great deal to the knowledge of the total energy requirements of children of different ages.

The first work on children and adults in which special care was taken to keep the subject as inactive as possible and in a postabsorptive state was that reported in 1899 by Magnus-Levy and Falk.[7] The healthy subjects studied by these workers included 8 boys and 7 girls between 2 and 12 years of age, inclusive. The tests were made with a Geppert-Zuntz apparatus, which required the use of a nose clip and mouthpiece. The inspired and the expired air were separated by means of valves. The expired air was measured with a meter and then analyzed in duplicate for carbon dioxide and oxygen. Each test period lasted from sixty to eighty minutes and was divided into two parts to give check determinations. Usually from 3 to 6 satisfactory tests were made on each subject. The authors recognized the error that could be introduced by overventilation or underventilation of the lungs and considered only those tests during which the respiration was believed to be normal. They also realized the importance of training their subjects, and preliminary tests were made whenever it was possible. The authors found that the gaseous exchange of children when referred to weight or to square meters of body surface, as calculated by Meeh's[8] formula, was considerably higher than that of adults and that the younger the child the greater was the difference observed. They concluded, therefore, that age influences the energy metabolism as well as other physiologic performances and that Rubner's[9] body surface law is not valid for all ages.

In 1915, Olin[10] reported studies on the carbon dioxide production of 70 boys between 9 and 12 years of age, inclusive. The boys were

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4. Forster, V., in von Ziemssen, H.: Handbuch der Hygiene, Leipzig, F. C. W. Vogel, 1882, vol. 1, p. 76; cited by Benedict and Talbot.[1]

5. Speck, C.: Physiologie des menschlichen Athmens nach eigenen Untersuchungen, Leipzig, F. C. W. Vogel, 1892; cited by Benedict and Talbot.[1]

6. Sondén, K., and Tigerstedt, R.: Untersuchungen über die Respiration und den Gesammtstoffwechsel des Menschen, Skandinav. Arch. f. Physiol. **6:1**, 1895.

7. Magnus-Levy, A., and Falk, E.: Der Lungengaswechsel des Menschen in den verschiedenen Altersstuffen, Arch. f. Anat. u. Physiol., supp., 1899, p. 314.

8. Meeh, K.: Oberflächenmessungen des menschlichen Körpers, Ztschr. f. Biol. **15:**425, 1879; cited by Benedict and Talbot.[1]

9. Rubner, M.: Ueber den Einfluss der Körpergrösse auf Stoff- und Kraftwechsel, Ztschr. f. Biol. **19:**535, 1883; cited by Magnus-Levy and Falk.[7]

10. Olin, H.: Ueber die Kohlenstoffabgabe bei Knaben im Alter von 10 bis 18 Jahren, Skandinav. Arch. f. Physiol. **34:**414, 1916.

studied individually in a large respiration chamber. The experiments lasted for two hours and were made while the subjects, who had had a small breakfast, sat quietly in a chair reading. The data from these experiments are not comparable with those obtained on fasting and reclining subjects.

In 1917 Aub and Du Bois,[11] in one of a series of reports from the Russell Sage Institute of Pathology, suggested a curve to show the trend of the basal metabolism of normal persons from birth through old age. For the interval from 2 to 12 years, inclusive, the data for the curve consisted of those of Magnus-Levy and Falk[7] and those obtained by Du Bois on 4 boy scouts aged 12 years.[12] The heat production of the boy scouts was measured by both direct and indirect calorimetry with the Russell Sage respiration calorimeter.[13] The boys were allowed a small breakfast from three and one-half to four hours before the experiment was started, in order that they might not be irritable from hunger, and a preliminary rest period of one hour was observed. A two hour experimental period was used because the boys could not be kept quiet for the usual three hours. During one of the experimental hours the boys were allowed to read quietly. In each test reported, the work adder indicated less than 15 cm. per hour, a figure which represented the average movement of a subject who turned over once or twice an hour and shifted his position a few times to become more comfortable. The calories derived from protein were calculated from specimens of urine voided between 9 a. m. and 1:15 p. m., since it was not possible to secure twenty-four hour specimens. Evidently no other investigation on normal children between 2 and 12 years of age, inclusive, has been undertaken at the Russell Sage laboratory. When the series of studies on basal metabolism was being organized, Gephart and Du Bois said:[14] "It was the original intention to use a large number of normal subjects and determine the individual variations in metabolism, but this laborious piece of work was gladly abandoned when it was learned that Benedict and his collaborators were engaged in the task."

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11. Aub, J. C., and Du Bois, E. F.: Clinical Calorimetry: XIX. The Basal Metabolism of Old Men, Arch. Int. Med. **19**:823 (May) 1917.

12. Du Bois, E. F.: Clinical Calorimetry: XII. The Metabolism of Boys Twelve and Thirteen Years Old Compared with the Metabolism at Other Ages, Arch. Int. Med. **17**:887 (June) 1916.

13. Riche, J. A., and Soderstrom, G. F.: Clinical Calorimetry: II. The Respiration Calorimeter of the Russell Sage Institute of Pathology in Bellevue Hospital, Arch. Int. Med. **15**:805 (May) 1915.

14. Gephart, F. C., and Du Bois, E. F.: Clinical Calorimetry: IV. The Determination of the Basal Metabolism of Normal Men and the Effect of Food. Arch. Int. Med. **15**:835 (May) 1915.

The studies on basal metabolism undertaken by the workers at the Nutrition Laboratory in Boston included observations on many children. From earlier experience, the directors of this investigation decided that they would be unlikely to obtain data regarding the normal metabolism of children if hospital patients were used. Accordingly, they made arrangements to establish a respiration laboratory at the New England Home for Little Wanderers. In a monograph published in 1921, Benedict and Talbot [1] reported the results obtained on the children studied at the home. In 1933 Talbot [15] stated that the data on the subjects under 8 years of age were obtained with the Benedict cot chamber method [16] and those on the older children, for the most part, with a Benedict portable apparatus. Whenever possible the tests were made with the children asleep and in a postabsorptive state. In the report published in 1921 the authors did not definitely designate in all cases whether the subject had been fed, but in 1933 Talbot [15] stated that only the children under 2 years of age had been given food before the test was made. Except in the case of 1 girl, subject 145, no information was given as to whether the child was asleep or awake during the test. The authors reported only that in many instances the older children were awake. The recorded readings were begun when the pulse rate and activity tracing showed that the subject was relaxed and absolutely quiet. The readings were continued for a varying number of twenty to thirty minute periods, depending on the continued inactivity of the subject. Only the minimal values were reported. The study included 66 tests on 34 girls and 62 tests on 49 boys between the ages of 2 and 12 years, inclusive, and 23 children were observed for periods varying from a few months to three years.

Since only a small amount of data on girls between 12 and 18 years of age, inclusive, was available and the slope of the line representing the change in the metabolism of women [17] and that of the line showing the trend of the basal metabolism of girls under 12 years of age [1] were not the same, a series of experiments on girl scouts was undertaken at the Nutrition Laboratory. The data obtained from this

15. Talbot, F. B.: Interpretation of Basal Metabolism of Children, J. Pediat. **3**:247 (July) 1933.

16. Benedict, F. G., and Talbot, F. B.: The Gaseous Metabolism of Infants, with Special Reference to Its Relation to Pulse-Rate and Muscular Activity, Publication 201, Carnegie Institution of Washington, 1914.

17. (*a*) Benedict, F. G.; Emmes, L. E.; Roth, P., and Smith, H. M.: The Basal, Gaseous Metabolism of Normal Men and Women, J. Biol. Chem. **18**:139, 1914. (*b*) Harris, J. A., and Benedict, F. G.: A Biometric Study of Basal Metabolism in Man, Publication 279, Carnegie Institution of Washington, 1919.

work were reported by Benedict and Hendry [18] in 1921. The girls were selected on the basis of their being "presumably in good health and normal." To substantiate their normalcy, their heights and weights were compared with the Wood height-weight standards.[19] They were given a light supper at the laboratory and were entertained quietly during the evening. The carbon dioxide produced by the group was measured while the girls, 12 at a time, were in deep sleep in a large respiration chamber. It usually reached a minimum between 12:30 and 1:30 a. m. A value of 3.086 calories per gram of carbon dioxide produced, corresponding to an average respiratory quotient of 0.79, was used in the calculation of the heat production. Two groups of 12 girls each, whose ages averaged 12 years and 2 months in one case and 12 years and 10 months in the other, were included in the series.

In 1933 Benedict and Meyer [20] determined the basal metabolism of 18 American-born Chinese girls between the ages of 12 and 22 years, inclusive. The tests were made in the morning under standard conditions with a helmet respiration apparatus and an external blower and carbon dioxide absorber. Each subject was studied on from two to five different days within two weeks. The state of nutrition of the subjects compared favorably with that of the girl scouts, and the pelidisi calculated by the von Pirquet method [21] gave values between 80 and 100, with a mean of 92. Three girls under 13 years of age were included in the series.

In 1932 Talbot [22] reported studies on the basal metabolism of 18 sets of twins, which included 3 sets of boys and 4 sets of girls between the ages of 2 and 12 years, inclusive, if the children being treated for epilepsy were excluded. The 14 children were healthy subjects, on whom tests were made while they were in a basal condition. The tests were made at the Massachusetts General Hospital, on the older children with a Benedict portable apparatus and on the infants with a chamber apparatus.

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18. Benedict, F. G., and Hendry, M. F.: The Energy Requirements of Girls from Twelve to Seventeen Years of Age, Boston M. & S. J. **184**:217 (March 3); 257 (March 10); 282 (March 17); 297 (March 24); 329 (March 31) 1921.

19. Gray, H., and Gray, K. M.: Normal Weight, Boston M. & S. J. **177**:894 (Dec. 27) 1917.

20. Benedict, F. G., and Meyer, M. H.: The Basal Metabolism of American-Born Chinese Girls, Chinese J. Physiol. **7**:45 (March) 1933.

21. Robertson, T. B.: Growth and Development, in Abt, Isaac A.: Pediatrics, Philadelphia, W. B. Saunders Company, 1923, vol. 1, p. 508.

22. Talbot, F. B.: Basal Metabolism of Twins, New England J. Med. **207**:318 (Aug. 18) 1932.

In 1921 [23] and again in 1925 [24] Talbot published prediction standards for boys and girls which were derived from the original data of Benedict and Talbot.[1] In 1935 Talbot, Wilson and Worcester [25] presented standards for girls based on the early work of Benedict and Talbot [1] and also on new data, on 87 normal girls from private schools. No individual or collective data on the girls from private schools were given.

Klein, Müller, and Steuber [26] reported, in 1921, 4 standard metabolism tests on 2 boys 7 years old. The boys were of approximately the same age, weight and height. The respiratory exchange was measured by analyzing the air in a nonventilated chamber at the beginning of a ten hour period and again at the end of the period. The boys were studied together and were supposed to be sleeping during the experiments, but according to the notes taken by the authors they were often restless.

In 1924 the same authors [27] reported a series of tests on 12 boys from 7 to 10 years of age, inclusive. The subjects were divided into 6 groups of 2 each on the basis of age, height and weight. The experimental procedure was the same as that in the previously mentioned work.

Bedale [28] in 1923, in order to determine the total energy expenditure and food requirements of children, measured the basal metabolism of several pupils of the Bedale School in Hampshire, England. The respiratory exchange was obtained by means of a Douglas bag and a Haldane gas analysis apparatus. The tests were made at 6:45 in the morning with the children in their own beds. The author discarded the tests in which there was definite evidence that the subject was dozing or asleep. Eight boys and 19 girls between 7 and 12 years of age, inclusive, were studied.

In 1923, Hobson,[29] working in Dreyer's laboratory, determined the basal metabolism of 1 boy who was 9 years old, 1 who was 11 years

23. Talbot, F. B.: Standards of Basal Metabolism in Normal Infants and Children, Am. J. Dis. Child. **21**:519 (June) 1921.

24. Talbot, F. B.: Basal Metabolism of Children, Physiol. Rev. **5**:477 (Oct.) 1925.

25. Talbot, F. B.; Wilson, E. B., and Worcester, J.: Standards of Basal Metabolism of Girls (New Data) and Their Use in Clinical Practice, J. Pediat. **7**:655 (Nov.) 1935.

26. Klein, W.; Müller, E., and Steuber, M.: Beitrag zur Kenntnis des energetischen Grundumsatzes bei Kindern, Arch. f. Kinderh. **70**:81 (Oct.) 1921.

27. Klein, W.; Müller, E., and Steuber, M.: Ein Beitrag zum Grundumsatz bei älteren Kindern, Arch. f. Kinderh. **74**:286 (July) 1924.

28. Bedale, E. M.: Energy Expenditure and Food Requirements of Children at School, Proc. Roy. Soc., London, s.B **94**:368, 1923.

29. Hobson, F. G.: A Comparative Study of Basal Metabolism in Normal Men, Quart. J. Med. **16**:363 (July) 1923.

old and 2 who were 12 years old. A Benedict apparatus supplied by the Sanborn Company was used, and a rest period of from thirty to sixty minutes preceded the test. The subjects were awake, reclining and in a postabsorptive state. Observations were made on each subject during two fifteen minute periods, and if the difference between the two readings exceeded 5 per cent, a third observation was made. The average oxygen consumption during the two satisfactory periods and a calorific value corresponding to an assumed respiratory quotient of 0.82 were used to calculate the heat production.

In the same year Fleming [30] reported studies made on a single child over a period of nine years, from the time the child was 1 year of age until he was 10. In an attempt to show the relationship of the rate of growth to the number of calories used in growth per kilogram per year, the author plotted both the number of calories used in growth and the increase in weight for one year per mean weight for that year against age. The number of calories used in growth was obtained by subtracting 28 calories, the basal value for adults, from the basal number of calories per twenty-four hours per kilogram and then multiplying the figure thus obtained by 365. No information is given concerning the method used, the experimental conditions or the sex of the subject.

In the summer of 1924 a survey as to the incidence of goiter in school children in Winnipeg, Canada, suggested the desirability of making basal metabolism tests on a large number of normal children. Of the 250 children subsequently tested by Cameron [31] (1925), 86 were classed as normal. A Sanborn Handy apparatus was used for all the determinations, and a preliminary test was made on the afternoon preceding the experimental day, in order that the child might become accustomed to the apparatus. The subjects were fasting and awake and were required to rest thirty minutes before the readings were recorded. Only one fifteen minute test, during which readings were taken at the beginning of each minute, was made on each child. The series included tests on 32 boys and 45 girls between 6 and 15 years of age, inclusive.

MacLeod [32] (1924) reported the results of 362 basal metabolism tests on 43 girls between the ages of 11 and 14 years, inclusive. Fifteen of the subjects were observed for two or three years. The reported data included the results of 59 tests on 29 girls under 13 years of age.

30. Fleming, G. B.: The Influence of Growth on the Basal Metabolism of Children, Am. J. Dis. Child. **25**:85 (Feb.) 1923.

31. Cameron, A. T.: Basal Metabolic Determinations in Two Hundred and Fifty Winnipeg School Children, Canad. M. A. J. **15**:1022 (Oct.) 1925.

32. MacLeod, Grace: Studies of the Normal Basal Energy Requirement, Columbia University, New York, 1924.

A Sanborn-Benedict portable respiration apparatus was used, and all the determinations were made with the subject in a postabsorptive state and after a rest period of approximately thirty minutes. Observations were made for at least 2 ten to twelve minute periods during each determination.

A preliminary report of studies in progress on normal school children between the ages of 5 and 17 years, inclusive, was made in 1925 by Sandiford and Harrington.[33] The series contained 231 determinations on 79 girls and 224 determinations on 78 boys. The children came to the laboratory without breakfast and were required to rest thirty minutes before the tests were begun. In most cases single tests were made on three consecutive days. The respiratory exchange was measured by means of a gasometer and a Haldane gas analysis apparatus. Since the study was still in progress at the time of their report, the authors thought it advisable not to calculate averages. In 1929 Boothby and Sandiford [34] published prediction standards for children over 5 years of age. The data from which these values were obtained consisted of those mentioned by Sandiford and Harrington and data on 105 additional children. These values are known as the Boothby and Sandiford modication of the Aub and Du Bois standards. The authors stated that individual data would be published in detail by Sandiford and Harrington, but apparently they have not yet appeared.

The Bailey [35] (1926) standards were based on a study of 254 boys and 220 girls between the ages of 4 and 20 years, inclusive. The apparatus used for the determinations consisted of a modified Tissot spirometer designed by the author and a modified Haldane-Henderson gas analysis apparatus. No individual data were reported.

The series of studies on energy metabolism reported by Wang, Kern, Frank and Hays [36] in 1926 was undertaken as part of a general program designed to overcome undernutrition in Chicago children. To discover whether variations would occur as a result of differences in locality and experimental conditions from the values obtained by Benedict and Talbot in Boston, determinations of the basal metabolism were

33. Sandiford, I., and Harrington, E. R.: Preliminary Report on the Basal Metabolism of One Hundred and Fifty-Seven Normal School Children Between the Ages of Five and Seventeen Years, J. Biol. Chem. **63**:xxxv (Feb.) 1925.

34. Boothby, W. M., and Sandiford, I.: Normal Values of Basal or Standard Metabolism: A Modification of the Du Bois Standards, Am. J. Physiol. **90**:290 (Oct.) 1929.

35. Bailey, C. V., quoted by Hawk, P. B., and Bergheim, O.: Practical Physiological Chemistry, ed. 9, Philadelphia, P. Blakiston's Son & Co., 1926, p. 896.

36. Wang, C. C.; Kern, R.; Frank, M., and Hays, B. B.: Metabolism of Undernourished Children: II. Basal Metabolism, Am. J. Dis. Child. **32**:350 (Sept.) 1926.

made on 9 normal girls from 4 to 11 years of age, inclusive. The fasting subject was allowed to rest thirty minutes before the beginning of the test, which consisted of duplicate determinations of thirty minutes each. A Benedict cot chamber equipped with a Benedict universal respiration apparatus was used for all the determinations. The child was subjected to a training period on the day previous to the first test, and tests were made on three consecutive days. Each set of figures reported was based on computations made from the average of the two lowest readings obtained. In all cases the child was awake but was kept as quiet as possible. Kymograph records of the activity were made.

Several years later, in 1932, Wang and Hawks [37] determined the basal metabolism of 11 Chinese boys and 7 Chinese girls between the ages of 5 and 12 years, inclusive, all of whom were born and reared in the United States. A Tissot gasometer and a Haldane gas analysis apparatus were employed in the measurement of the gaseous exchange. As before, the average of the two lowest values of the 3 tests performed was reported as representative of the basal metabolism of the child.

In 1934 Wang [38] determined the basal metabolism of 14 American girls between the ages of 12 and 20 years, inclusive, in order that she might compare the results with those reported by Benedict and Meyer [20] in 1933 on American-born Chinese girls of the same ages. Only 1 of the girls was under 13.

An interesting series of standard metabolism tests on girls was reported in 1926 by Blunt, Tilt, McLaughlin and Gunn.[39] The data had been collected over a period of several years. Tests on 22 of the girls were repeated in the second year and on 15 of the girls in the third year also. The subjects were all classed as physically normal by the school physician. The experimental procedure permitted a light breakfast at least four hours before the tests were made and required a preliminary half-hour rest period. The apparatus used was either a Sanborn or a Collins model of the Benedict portable respiration apparatus for the early experiments and a Benedict-Roth apparatus for the later experiments. Observations were made on each subject on two separate days, either consecutive or close together. The results for the two days were averaged if they checked within 5 per cent. If the

37. Wang, C. C., and Hawks, J. E.: Basal Metabolism of Twenty-One Chinese Children Reared or Born and Reared in the United States, Am. J. Dis. Child. **44**:69 (July) 1932.

38. Wang, C. C.: Basal Metabolism of American-Born Chinese Girls and of American Girls of Same Age, Am. J. Dis. Child. **48**:1041 (Nov.) 1934.

39. Blunt, K.; Tilt, J.; McLaughlin, L., and Gunn, K. B.: The Basal Metabolism of Girls, J. Biol. Chem. **67**:491 (Feb.) 1926.

agreement was not that close, the two lowest of all of the values obtained for a ten minute period were averaged. This course was followed on the advice of Dr. Benedict. The experiments extended from 1922 to 1925 and included determinations on 53 girls between 7 and 12 years of age, inclusive.

Most of the older children studied by Levine and Wilson [40] (1926) were definitely diseased, and since all were hospital patients it is doubtful whether any of them should be classed as normal, healthy children.

In 1926 Göttche,[41] while attempting to observe the influence of puberty on the specific dynamic action of a constant diet, determined the basal metabolism of 34 normal children, 12 boys and 22 girls, between 3 and 12 years of age, inclusive. The determinations were made with a Krogh apparatus and while the subjects were awake and in a postabsorptive condition.

In 1931 Bierring [42] stated that the basal metabolic standards universally used in Germany were those of Kestner and Knipping [43] (1928). The latter authors modified the multiple prediction formulas of Harris and Benedict [17b] and extended them to include children of all ages and both sexes. The modifications were based on unpublished original observations of their own and on the data of other workers. Three or 4 fifteen minute tests on each subject were made under rigorously maintained basal conditions and with the Knipping modification of the Benedict respiration apparatus. The only information available concerning the number of subjects studied is the statement of Bierring that around 150 boys between 7 and 18 years of age, inclusive, were examined.

In 1926 Schadow [44] determined the basal metabolism of 75 children, free from endocrine disturbance, between the ages of 5 and 20 years, inclusive. The results were compared with the Kestner and Knipping multiple prediction standards.

In 1927 Lax and Petényi,[45] in studying the reaction during puberty, determined the basal metabolism of 30 children between the ages of

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40. Levine, S. Z., and Wilson, J. R.: The Respiratory Metabolism in Infancy and in Childhood: Basal Metabolism of Children, Am. J. Dis. Child. **31**:323 (March) 1926.

41. Göttche, O.: Gasstoffwechseluntersuchungen im Kindesalter: Die Pubertätsreaktion, Monatschr. f. Kinderh. **32**:22, 1926.

42. Bierring, E.: The Standard Metabolism of Boys (Seven to Eighteen Years, Inclusive), Copenhagen, Levin & Munksgaard, 1931.

43. Kestner, O., and Knipping, H. W.: Die Ernährung des Menschen, Berlin, Julius Springer, 1926 and 1928.

44. Schadow, H.: Gaswechseluntersuchungen im Kindes- und Pubertätsalter, Monatschr. f. Kinderh. **34**:145, 1926.

45. Lax, H., and Petényi, G.: Der Grundumsatz im Pubertätsalter, Monatschr. f. Kinderh. **36**:385, 1927.

10 and 16 years, including 15 between 10 and 12 years of age, inclusive. The tests were made with a Krogh apparatus and with the children in a postabsorptive state. Although the authors did not include the sex of the subjects in the data reported, it can be deduced from the standard values used for comparison that all the subjects were girls.

In 1928 Klugh [46] measured the basal metabolism of 26 apparently normal white American school children of Atlanta, Ga., between the ages of 6 and 12 years, inclusive. The tests were made under approved standard conditions with a Sanborn apparatus. Fourteen of the children were given from 2 to 4 tests. No individual data were published.

In 1928 Rosenblüth [47] reported studies on the basal metabolism of 84 normal schoolboys between the ages of 11 and 19 years, inclusive. The tests were carried out with a Krogh respiration apparatus that had been modified slightly by the author. Only the lowest value obtained for each boy was reported. The studies included observations on 23 subjects under 13 years of age.

In 1929 Lucas and his co-workers undertook a series of studies on the basal metabolism of a large number of children, and in 1932 Lucas, Pryor, Bost, Pope and Henderson [48] reported the completion of 1,027 tests on 573 subjects between the ages of 3 and 18 years, inclusive. In 1933 Lucas, Pryor, Bost and Pope [49] reported parallel studies on the body build and the basal metabolism of 415 children. From their data they calculated the mean percentage deviation from the Benedict and Talbot standards of observations on 169 girls and 140 boys between the ages of 3 and 9 years, inclusive, and on 134 girls and 130 boys between the ages of 10 and 18 years, inclusive. They also studied the relationship of allergy to basal metabolism in a group of 72 children. In the same year Lucas and Pryor [50] published averages for the heat production of children between the ages of 3 and 18 years, inclusive. The values were derived from 932 observations on 932 subjects, including 305 boys and 401 girls under 13 years of age. The tests were all made with a Benedict-Roth apparatus and under standard conditions.

46. Klugh, G. F.: Basal Metabolism in Normal Children from Six to Twelve Years of Age, J. A. M. A. **91**:202 (July 21) 1928.

47. Rosenblüth, A.: Der Grundumsatz bei Kindern und Jugendlichen, Ztschr. f. Kinderh. **46**:531, 1928.

48. Lucas, W. P.; Pryor, H. B.; Bost, C.; Pope, S. T., and Henderson, M. C.: Growth Problems and Their Relation to Zones of Normal Physiologic Reactions, J. Pediat. **1**:572 (Nov.) 1932.

49. Lucas, W. P.; Pryor, H. B.; Bost, C., and Pope, S. T.: Growth Problems: II. Basal Metabolic Rate Variations in Relation to Body Build, Adolescence and Allergy in Children, J. Pediat. **3**:856 (Dec.) 1933.

50. Lucas, W. P., and Pryor, H. B.: The Body Build Factor in the Basal Metabolism of Children, Am. J. Dis. Child. **46**:941 (Nov.) 1933.

Nylin,[51] in 1929, in his study of the periodic variations in the growth, the standard metabolism and the oxygen capacity of the blood in children, determined the standard metabolism of 3 boys and 5 girls between 4 and 7 years of age, inclusive. The observations on each subject were made at two month intervals for a year. Usually each child was examined on six consecutive days in each two month period. The subjects were normal preschool children from workingmen's homes in Spånga, Sweden. The tests were made after a thirty minute rest period with a Krogh respiration apparatus equipped with a special mouthpiece arrangement suitable for children and with the children in a postabsorptive state.

In 1930 Collins and McClendon [52] determined the basal metabolism of 4 boys and 2 girls on whom Boyd had made body surface studies. The children attended the nursery school conducted by the Institution of Child Welfare of the University of Minnesota and were apparently healthy. The fasting subjects were brought to the laboratory by automobile in the early morning, and after a rest period of thirty minutes the tests were made with a Benedict-Roth apparatus. Several tests were made on each child at intervals of not more than three days. Basal conditions were not maintained during any of the tests on 2 of the boys

To observe the influence of puberty on basal metabolism, Topper and Mulier [53] undertook studies on the metabolism of boys and girls between the ages of 10 and 16 years, inclusive. In 1932 they reported observations on 28 girls and 10 boys. The tests were made under standard conditions with a Krogh respirometer or a Benedict-Roth apparatus and were repeated at intervals of from six to twelve months for periods ranging from one to four years. One practice test was made several days before the first recorded test. The nutritional state of each subject was expressed by the Pirquet pelidisi. If the cases in which there was a question of disease are excluded, the series contained 36 tests on 17 girls and 8 tests on 6 boys between the ages of 10 and 12 years, inclusive.

One of the largest and most carefully executed pieces of work reported in this field in recent years is that of Bierring,[42] in 1931, on 133 Copenhagen schoolboys between the ages of 7 and 18 years, inclusive. The subjects were described as average schoolboys chosen

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51. Nylin, G.: Periodical Variations in Growth, Standard Metabolism, and Oxygen Capacity of the Blood in Children, Acta med. Scandinav., supp. 31, 1929, p. 1.

52. Collins, D. A., and McClendon, J. F.: Basal Metabolic Rate and Surface Area of Children Between the Ages of Three and Five Years, Arch. Pediat. **47**:521 (Aug.) 1930.

53. Topper, A., and Mulier, H.: Basal Metabolism of Normal Children: The Puberty Reaction, Am. J. Dis. Child. **43**:327 (Feb.) 1932.

at random. All determinations were made with the boys awake, recumbent and in a postaborptive state. A rest period of at least thirty minutes with the subject in a sitting position preceded the test, and continuous observation by one of the workers helped to keep the subject quiet and relaxed throughout the test. The oxygen consumption, determined by means of a Krogh apparatus, was measured on several successive days until at least four experimental periods gave no evidence of further decrease. Fifty-five determinations of the respiratory quotient of 21 boys gave values which varied between 0.80 and 0.91, with a mean of 0.85. An apparatus similar to that of Voit and Pettenkofer and a Krogh modification of the Haldane gas analysis apparatus were used in the studies on the respiratory quotient. Only the tests throughout which the respiration was normal and for which the gas analyses checked within 0.05 per cent for both oxygen and carbon dioxide were retained. The number of calories produced by each subject was calculated from the average oxygen consumption of the four comparable periods by the use of a calorific value of 4.86, which corresponds to a nonprotein respiratory quotient of 0.85. The study included 311 tests on 61 boys under 13 years of age.

In 1933 Klotz [54] reported studies on the basal metabolism of healthy and sick children. Tests were made on each subject in several different climatic situations. The determinations, which included 11 tests on 4 healthy girls and 19 tests on 5 healthy boys between the ages of 8 and 12 years, inclusive, were performed with a Knipping apparatus and under basal conditions.

In 1933 Kerley [55] reported studies on the basal metabolism of 31 children without illness that would affect the metabolism, on 12 cretins and on 52 children in whom obesity was the outstanding pathologic condition. The tests were made with a Sanborn apparatus after a twenty minute rest period and with the children in a postabsorptive state. No data were included in the report other than a table to show the response of 1 subject to thyroid therapy.

It is doubtful if any of the subjects concerning whom data were reported by Püschel [56] in 1933 should be classed as normal healthy children.

Studies on the basal metabolism of 52 boys and 47 girls from 8 to 18 years of age, inclusive, each weighing more than 24 Kg., were reported

54. Klotz, M.: Untersuchungen des Grundumsatzes gesunder und kranker Kinder an der Ostsee und Nordsee, Monatschr. f. Kinderh. **57**:239, 1933.

55. Kerley, C. G.: Basal Metabolism Studies in Obesity in Children, J. Pediat. **2**:729 (June) 1933.

56. Püschel, E.: Des Atemäquivalent bei Kindern im Nüchternzustand und nach Nahrungsaufnahme, Monatschr. f. Kinderh. **57**:349, 1933.

by de Bruin [57] in 1933. The determinations were made with the apparatus of Dusser de Barenne and Burger. The curves of standard values for Dutch children weighing less than 24 Kg. as well as those for the larger children are included in the report.

In 1934 Molitch and Cousins [58] reported studies on the basal metabolism of 200 inmates of the New Jersey State Home for Boys between the ages of 9 and 18 years, inclusive. The tests were made under standard conditions with a Sanborn Motor-Grafic apparatus. Forty-three boys between the ages of 9 and 12 years, inclusive, were observed. Successive determinations were made every twenty-four hours until not more than a 4 per cent difference was obtained for the oxygen consumption. Boys with evident endocrine disturbance were not used in the study.

Recently (1934) Robb [59] published in monograph form the results of her studies on the energy requirement of normal 3 and 4 year old children. Studies on basal metabolism, consisting of 17 tests on 11 girls and 12 tests on 9 boys were made with a Benedict and Benedict student respiration apparatus.[60] The child was connected to the apparatus by a mouthpiece and nose clip. The subjects were children from the nursery school of the Child Development Institute, Teachers College, Columbia University, and were reported to be in very good physical condition by the school pediatrician. They were brought to the laboratory early in the morning on three different days, and after a rest of from twenty to thirty minutes the test was begun; it consisted of two periods of from six to ten minutes. The volume of oxygen representative of the basal metabolism of the subject was determined in the following way: "If the lowest figure obtained was checked within 5 per cent by the last two periods on two different mornings, the average was used as the basal value." The calories expended were computed from the oxygen consumption and the assumed nonprotein respiratory quotient of 0.82.

Fifty-six average Japanese children, 17 boys and 17 girls between the ages of 3 and 6 years, inclusive, and 9 boys and 13 girls between the ages of 7 and 11 years, inclusive, served as subjects for studies on

57. de Bruin, M.: Onderzoekingen over de Gasstofwisseling bij Kinderen, Nederl. tijdschr. v. geneesk. **77**:5684, 1933.

58. Molitch, M., and Cousins, R. F.: Variation of Basal Metabolic Rate per Unit Surface Area with Age, J. Nutrition **8**:247 (Aug.) 1934.

59. Robb, E.: The Energy Requirement of Normal Three- and Four-Year-Old Children, Child Development Monograph 16, New York, Columbia University Press, 1934.

60. Benedict, F. G., and Benedict, C. G.: Mental Effort in Relation to Gaseous Exchange, Heart Rate, and Mechanics of Respiration, Publication 446, Carnegie Institution of Washington, 1933.

basal metabolism conducted by Nakagawa [61] in the autumn of 1932 and reported in 1934. A Benedict respiration apparatus with a cot chamber was used, and all tests were made with the subject in a post-absorptive state, in the early morning and after a rest period of at least thirty minutes. The children were subjected to some preliminary training. The urinary nitrogen was determined from specimens of urine collected before and after each experiment.

From the same subjects Nakagawa [62] in 1935 selected 26 cooperative children, on whom he made determinations of the basal metabolism at two month intervals for a year. The experiments, for which the procedure was the same as that previously reported, included 67 tests on 11 boys between 3 and 10 years of age, inclusive, and 95 tests on 15 girls between 4 and 11 years of age, inclusive.

To note any relationship between the basal metabolism of children and their mental status, Rothbart [63] in 1935 determined the basal metabolism of 59 boys and 39 girls whose intelligence quotients, according to the Stanford-Binet system, ranged between 60 and 120. The children were inmates of the Michigan State School for Children at Coldwater, Mich., and slept in the hospital the night preceding the experimental day. Each test consisted of two six minute observations made under standard conditions with a Benedict-Roth apparatus. Tests were repeated on subsequent days until it was thought that the "best conditions were met." The lowest value obtained in any period was regarded as representative of the basal metabolism of the subject. If the subjects with an intelligence quotient under 80 or with a pathologic disturbance were eliminated, the series included 20 boys and 20 girls between the ages of 8 and 12 years, inclusive.

Several reports of studies on the basal metabolism of children with abnormal body proportions are found in the literature, but they have not been considered in this review, since our report deals only with the basal metabolism of normal, healthy children.

The results obtained in the various studies mentioned have not been discussed in our review of the literature, since they can be most easily studied in a group and in relation to a single standard. They will be considered, in comparison with the data collected on the children of

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61. Nakagawa, I.: Growth and Basal Metabolism: I. Basal Metabolism of Preschool Children, Am. J. Dis. Child. **47**:963 (May) 1934; II. Basal Metabolism of Elementary School Children, ibid. **48**:35 (July) 1934.

62. Nakagawa, I.: Growth and Basal Metabolism: IV. Changes in the Basal Metabolism of Children During a Year, Am. J. Dis. Child. **49**:1232 (May) 1935.

63. Rothbart, H. B.: Basal Metabolism in Children of Normal and of Subnormal Intelligence with Blood Cholesterol and Creatinine Values, Am. J. Dis. Child. **49**:672 (March) 1935.

the Child Research Council, in the section of this report entitled Comment, which follows the presentation of the experimental results on these children.

EXPERIMENTAL PROCEDURE

Subjects.—Although the many different observations cited in the introduction are being made on the children of the Child Research Council, this paper presents the results only of the study on basal metabolism. The working plan of the metabolism unit calls for repeated basal metabolism tests on each child at three month intervals. With some of the subjects this schedule has been maintained; with others it has been impossible to adhere rigidly to such a program.

The method of selecting the experimental subjects presupposes a high degree of physiologic variation among the members of the group. However, the subjects have all been under observation for at least two years and have been classed by the members of the pediatric staff of the council as being within the vague borders of normality. In addition, conventional check of the normalcy of the subject has been made by comparing his observed height and weight with the tables of Woodbury for normal children, as presented by Grandprey,[64] and with those of Faber.[65] No marked deviation has been noted. The anthropometric studies have revealed no difference that has not been attributed to normal variation. Mentally, the children are definitely above the average.

Apparatus.—To obtain records of the energy metabolism of children during muscular repose, it is necessary to make the observations on sleeping subjects or to limit the time of experimentation to that during which the children can be reasonably contented and absolutely quiet while awake. The latter condition is the more easily obtained and is generally considered the standard state for determinations of the basal metabolism of subjects other than infants. However, it precludes the use of periods over an hour in length. In 1911 Howland,[66] by means of the small respiration calorimeter constructed by Williams,[67] showed that results obtained for comparatively short experimental periods by the indirect method of measuring the heat production of infants agreed closely with those obtained by the direct method. Evidence that the values secured for longer experimental periods by the two methods conformed was first reported by Rubner [68] and was confirmed later with the Atwater-Rosa-Benedict calorimeter [69] and the calorimeter used at the Russell Sage Institute of Pathology.[13] The cot chamber method of the closed circuit type described by Benedict and Tompkins [70] in 1916

64. Grandprey, M. B.: Range of Variability in Weight and Height of Children Under Six Years of Age, Child Development **4**:26 (March) 1933.

65. Faber, H. K.: A Weight Range Table for Children from Five to Ten Years of Age, Am. J. Dis. Child. **38**:758 (Oct.) 1929.

66. Howland, J.: Der Chemismus und Energieumsatz bei schlafenden Kindern, Ztschr. f. physiol. Chem. **74**:1 (Aug.) 1911.

67. Williams, H. B.: Animal Calorimetry: I. A Small Respiration Calorimeter, J. Biol. Chem. **12**:317, 1912.

68. Rubner, M.: Die Quelle der tierischen Wärme, Ztschr. f. Biol. **30**:73, 1894.

69. Atwater, W. O., and Benedict, F. G.: A Respiration Calorimeter with Appliances for the Direct Determination of Oxygen, Publication 42, Carnegie Institution of Washington, 1905.

70. Benedict, F. G., and Tompkins, E. H.: Respiratory Exchange, with a Description of a Respiration Apparatus for Clinical Use, Boston M. & S. J. **174**: 939 (June 29) 1916.

is based on the theory of indirect calorimetry and has been very satisfactory for the determination of the basal metabolism of small children. In 1930 Higgins and Bates [71] described an open circuit chamber method by which the observation could be completed in as short a time as thirty minutes. By this method, as a result of the extreme accuracy of the Carpenter [72] modification of the Haldane gas analysis apparatus for the determination of carbon dioxide and oxygen, it was possible to use sampling periods as short as one minute without sacrificing the accuracy of the whole procedure.

The method used in the studies of the Child Research Council is the open circuit chamber type described by Higgins and Bates.[71] Since the chambers differ in structure from the chamber used by Higgins and Bates at the Massachusetts General Hospital,[1] it may be well to describe them in detail. The three chambers,[73] designed to accommodate subjects of from small infant size to adult size, in order that the same technic may be used throughout the whole period of observation, are similar in structure and have the following respective dimensions: width, 35.7, 46 and 55.6 cm.; depth, 30.5, 35.3 and 41.4 cm.; length, 91.5, 137.7 and 200 cm., and volume corrected for the mattress, 68.8, 176.8 and 374.4 liters. Only the two larger chambers were used in the tests reported in this paper.

The cover of the chamber contains an observation window at the head end and an opening through which a thermometer can be inserted. The chamber is made air tight when it is closed, by means of screw clamps that press the cover onto a soft rubber seal fitted into a groove in the flange around the top of the chamber proper. To prevent contamination of the incoming air with car exhaust gases, the outdoor air inlet pipe extends to the top of the building. The air is drawn through the chamber by a blower connected to an electric motor. It enters just under the cover at the head and through a perforated distributor tube and leaves through a similar tube near the floor of the chamber at the foot end. It has been found that no accessory mechanism is necessary to insure effective circulation of the air.[40] The external portion of the outlet pipe is equipped with a metal stopcock, the adjustment of which regulates the rate of ventilation and thus eliminates the necessity of a rheostat on the motor. For the study under discussion the source of electricity was the hospital power plant, and the speed of the original motor was found to vary with the load thrown into the circuit. To secure a constant rate of ventilation, the motor furnished by the manufacturer was replaced by a larger, synchronized motor. The air coming from the chamber is collected in a calibrated gasometer of the Tissot type, which has been described in detail by Bailey.[74] The medium-sized chamber and the gasometer are shown in figure 1.

The gas samplers (fig. 2) are somewhat different from any previously described. They consist of large glass cylinders with a capacity of approximately 700 cc. and a two way stopcock at one end and a simple stopcock at the other end.

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71. Higgins, H. L., and Bates, V.: New Method for the Determination of the Basal Metabolism of Babies and of Small Children, Am. J. Dis. Child. **39**:71 (Jan.) 1930.

72. (*a*) Carpenter, T. M.: An Apparatus for the Exact Analysis of Air in Metabolism Investigations with Respiratory Exchange Chambers, J. M. Research **4**:1, 1923. (*b*) Carpenter, T. M.; Fox, E. L., and Sereque, A. F.: The Carpenter Form of the Haldane Gas Analysis Apparatus, J. Biol. Chem. **83**:211 (July) 1929.

73. The two smaller chambers were manufactured by Warren E. Collins, Inc. The large chamber was made locally.

74. Bailey, C. V.: Apparatus Used in the Estimation of Basal Metabolism. J. Lab. & Clin. Med. **6**:657 (Sept.) 1921.

The two way stopcock makes it possible, before a new sample of air is taken from the sampler into the gas analysis apparatus, to remove in a single operation all the air in the tubes which connect the sampler with the gas analysis apparatus and also the residual gases remaining in the calibrated buret from the previous determination. The capacity makes it possible to obtain gas for three analyses from one sampler in case it is necessary to repeat an analysis. The analyses are made with a Carpenter [72] modification of the Haldane gas analysis apparatus.

Calibration and Check of the Apparatus.—Chambers: The chambers were tested for leaks by forcing compressed air into the interior while all places

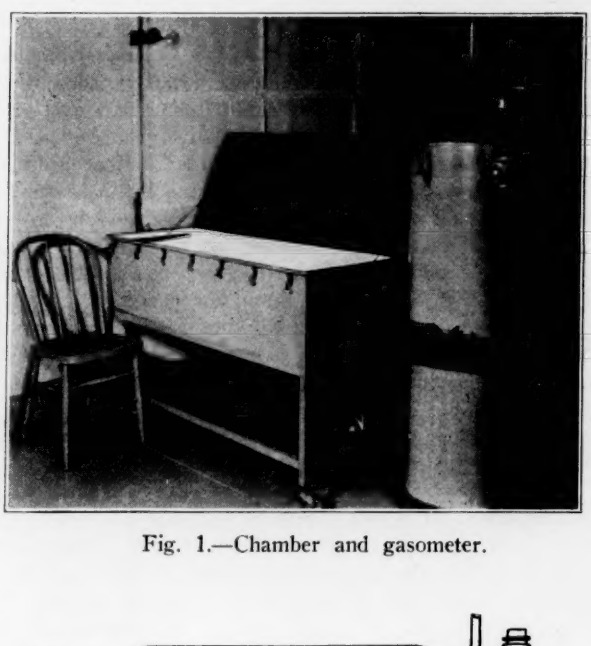

Fig. 1.—Chamber and gasometer.

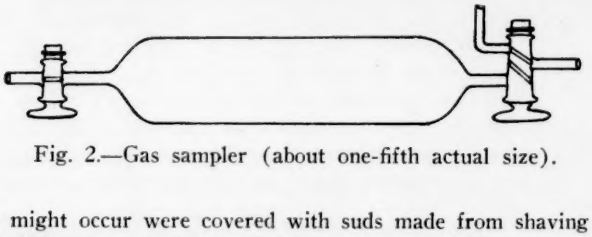

Fig. 2.—Gas sampler (about one-fifth actual size).

where leaks might occur were covered with suds made from shaving soap. The absence of bubbles showed all the chambers to be air tight.

Gas Analysis Apparatus: The measuring burets of the two gas analysis apparatus were calibrated with mercury. To assure minute control of the flow of mercury, a stopcock with a fine capillary point was fused to the lower end of the buret. A leveling bulb was attached to the stopcock by pressure tubing, was filled with mercury and was raised to bring the level of the mercury above the upper stopcock of the buret, after which the lower stopcock was closed and the leveling bulb removed. The calibration for individual graduations was then carried out as suggested by Carpenter.[72a]

Analyses of Outdoor Air: To be sure that the apparatus are in perfect working order at all times, analyses of the outdoor air are made at frequent intervals.

The outdoor air is drawn through the chamber and collected in the gasometer, from which samples are removed for analysis. Table 1 gives the results of the 149 analyses completed between February 1932 and April 1, 1936. The carbon dioxide values vary between 0.027 and 0.033 volumes per cent and the oxygen values between 20.935 and 20.949 volumes per cent, with a mean of 0.030 and 20.942 volumes per cent, respectively. These mean values were used in the computation of all the respiratory quotients reported in this paper. The mean values reported by Carpenter [72a] are 0.030 ± 0.003 volumes per cent for carbon dioxide and 20.940 ± 0.005 volumes per cent for oxygen.

Alcohol Checks: Alcohol checks are made less often than analyses of the outdoor air. Until recently the procedure consisted of burning an unknown amount of ethyl alcohol from the asbestos wick of a small alcohol lamp placed inside one of the chambers. The ventilation was regulated so that the proportion of carbon dioxide and oxygen inside the chamber was comparable to that which existed during a determination of metabolism. The air passing from the chamber was collected in the gasometer; samples were removed for analysis of the carbon dioxide and the oxygen content, and the respiratory quotients were calculated. The respiratory quotients from 81 determinations completed between April 1932 and November 1935 are given in table 2. They vary between 0.654 and 0.680, with a mean of 0.666 (theoretical, 0.667). Recently, a method has been devised by which the amount of alcohol burned may be determined and the theoretical amount of carbon dioxide produced and of oxygen consumed may be compared with the amounts which are actually obtained. The apparatus was constructed from the reservoir and lamp of a Jones [75] alcohol check apparatus for the calibration of the closed circuit bedside type of basal metabolism apparatus. The alcohol burns from a metal tip inside the chamber and is measured by means of a microburet on the outside of the chamber; otherwise the procedure is similar to that previously described. After a preliminary period, during which the carbon dioxide is building up in the chamber, samples of air are collected for analysis. Two samples are taken during the burning of each measured amount of alcohol. The samples are analyzed for carbon dioxide and oxygen, and the total amount of carbon dioxide produced and of oxygen consumed are computed. Table 3 shows the results of three such checks and the percentage variation from the theoretical. Since no change in technic was effectuated during our study, there is no reason to believe that the accuracy of the procedure was ever less than that demonstrated by these checks.

Gasometer: The bell of the gasometer was calibrated by measuring the inside circumference at the bottom with steel tapes. The values obtained for the circumference with three different steel tapes were 106.7 cm., 106.6 cm. and 106.64 cm. The mean of the three, 106.65 cm., indicates a volume of 0.90513 liters for each rise of 1 cm. of the gasometer bell, provided the bell was uniform in diameter. To detect any variation in the diameter of the bell, the outside circumference was measured at several different positions along the length of the bell. The following values for the circumference were obtained: at the bottom, 107.25 cm.; 1 foot (30.48 cm.) from the bottom, 107.35 cm.; 2 feet (60.96 cm.) from the bottom, 107.35 cm., and near the top, 107.3 cm. The uniformity of the bell was also checked by observing the reading of the tape with the passage of each of five successive volumes of 0.5 cubic foot of air through a Sargent wet test meter, connected in series with a chamber and the gasometer. The air was drawn by means of the

75. Jones, H. M.: An Accuracy Check for Metabolism Apparatus, J. Lab. & Clin. Med. **14**:750 (May) 1929.

TABLE 1.—*Record of Analyses of the Outdoor Air*

Date	Carbon Dioxide, Volumes per Cent	Oxygen, Volumes per Cent
1932		
2/16	0.029	20.945
3/22	0.030	20.942
3/22	0.030	20.941
4/ 2	0.030	20.938
4/ 2	0.031	20.936
4/ 5	0.029	20.946
4/11	0.029	20.947
4/12	0.030	20.939
4/15	0.029	20.944
4/15	0.027	20.948
4/15	0.029	20.943
4/19	0.030	20.948
4/25	0.028	20.940
4/25	0.030	20.940
4/26	0.032	20.942
6/20	0.033	20.942
6/21	0.028	20.939
7/13	0.030	20.941
9/12	0.032	20.945
9/27	0.029	20.942
10/13	0.030	20.946
11/ 1	0.029	20.947
11/23	0.032	20.946
11/23	0.031	20.941
1933		
1/13	0.031	20.944
1/31	0.031	20.946
1/31	0.031	20.946
2/10	0.033	20.947
2/10	0.031	20.940
2/28	0.031	20.942
3/ 4	0.031	20.948
3/ 4	0.031	20.942
3/ 6	0.029	20.944
3/ 6	0.030	20.942
3/17	0.031	20.949
3/21	0.027	20.942
3/27	0.032	20.949
3/29	0.031	20.939
4/ 4	0.030	20.948
4/10	0.031	20.941
4/24	0.032	20.949
4/25	0.031	20.945
5/12	0.031	20.947
5/13	0.032	20.940
5/25	0.031	20.947
5/25	0.030	20.942
6/ 6	0.031	20.939
6/ 7	0.030	20.941
6/19	0.030	20.942
7/ 3	0.030	20.949
8/11	0.029	20.941
8/12	0.031	20.942
8/22	0.029	20.944
8/23	0.030	20.947
9/ 5	0.031	20.940
9/ 5	0.030	20.939
9/18	0.031	20.941
9/18	0.031	20.940
10/ 2	0.032	20.947
10/ 2	0.031	20.941
10/31	0.030	20.941
10/31	0.031	20.940
11/14	0.030	20.941
11/29	0.029	20.942
1934		
1/25	0.029	20.936
1/26	0.031	20.936
2/ 8	0.032	20.938
2/22	0.030	20.947
2/23	0.029	20.938
2/23	0.033	20.944
3/14	0.028	20.942
3/21	0.031	20.940
3/29	0.033	20.942
4/ 3	0.031	20.947
4/ 7	0.030	20.940
4/ 9	0.027	20.945
4/19	0.031	20.945
5/ 3	0.030	20.940
5/ 5	0.032	20.939
5/15	0.029	20.936
5/31	0.032	20.943
6/ 2	0.032	20.938
6/11	0.031	20.940
6/12	0.029	20.940
7/ 5	0.031	20.941
7/19	0.030	20.944
7/20	0.028	20.939
7/28	0.032	20.938
8/12	0.031	20.936
8/31	0.029	20.936
9/12	0.032	20.941
9/12	0.031	20.946
9/15	0.029	20.942
9/25	0.030	20.946
9/25	0.029	20.946
10/10	0.028	20.939
10/11	0.029	20.936
10/13	0.030	20.944
11/ 6	0.031	20.938
11/19	0.029	20.936
12/ 5	0.029	20.938
12/ 6	0.031	20.942
12/11	0.031	20.939
12/12	0.029	20.945
12/28	0.030	20.944
1935		
1/ 3	0.032	20.947
1/ 9	0.029	20.936
1/15	0.028	20.947
1/30	0.030	20.936
2/23	0.031	20.936
2/27	0.031	20.949
3/14	0.030	20.938
3/27	0.029	20.940
3/28	0.028	20.941
4/11	0.032	20.945
4/29	0.029	20.945
5/ 3	0.030	20.942
5/14	0.030	20.939
5/17	0.030	20.945
5/25	0.030	20.939
7/15	0.030	20.936
7/16	0.032	20.939
7/26	0.032	20.936
7/29	0.031	20.944
8/14	0.030	20.943
8/14	0.028	20.944
9/17	0.029	20.938
9/24	0.030	20.938
9/26	0.032	20.946
10/ 4	0.030	80.939
10/ 9	0.030	20.944
10/22	0.030	20.938
10/23	0.029	20.945
11/ 1	0.030	20.941
11/ 4	0.030	20.945
12/ 3	0.029	20.941
12/17	0.031	20.941
12/28	0.031	20.941
1936		
1/ 2	0.032	20.939
1/ 3	0.033	20.937
1/ 8	0.029	20.937
1/21	0.030	20.943
1/22	0.028	20.945
2/ 6	0.031	20.946
2/18	0.028	20.942
3/ 3	0.033	20.935
3/13	0.031	20.944
3/18	0.029	20.944
3/26	0.029	20.939
Mean	0.030	20.942

electric motor through the chamber, then through the meter and finally into the gasometer. The maximal variation from the mean of the volumes measured in the five different segments of the gasometer was ± 0.47 per cent. Thus it is

TABLE 2.—*Record of Alcohol Checks (Respiratory Quotients Only)*

Date	Respiratory Quotient	Number of Gas Analysis Apparatus
1932		
4/ 9	0.666	2
9/26	0.676	2
12/ 8	0.665	2
1933		
3/ 6	0.654	1
3/27	0.658	2
4/ 6	0.679	1
4/18	0.673	2
4/20	0.673	1
5/12	0.661	2
5/17	0.657	1
5/17	0.680	2
6/16	0.676	1
7/ 1	0.656	1
8/17	0.668	2
9/ 5	0.660	1
9/ 5	0.664	2
9/11	0.661	1
9/25	0.673	2
10/16	0.664	2
1934		
1/31	0.673	1
1/31	0.662	2
2/15	0.664	2
2/17	0.674	1
2/27	0.680	1
3/20	0.661	2
3/23	0.672	1
4/18	0.663	1
4/23	0.661	2
5/ 9	0.663	1
5/ 9	0.666	2
5/24	0.664	1
6/ 8	0.665	1
6/11	0.669	2
6/19	0.661	1
7/11	0.665	1
7/23	0.663	1
8/12	0.668	1
8/12	0.671	2
8/21	0.670	2
8/23	0.658	1
9/14	0.680	1
1934		
9/19	0.669	1
9/20	0.658	2
10/16	0.655	2
10/30	0.667	2
11/ 1	0.670	1
11/14	0.671	1
11/28	0.661	1
11/28	0.668	2
12/ 8	0.664	2
12/11	0.664	1
1935		
1/ 4	0.671	2
1/25	0.659	1
2/13	0.661	2
2/14	0.667	2
2/14	0.663	1
3/ 5	0.669	1
4/ 4	0.667	1
4/11	0.662	1
4/24	0.662	2
5/ 6	0.664	2
5/ 8	0.670	1
5/27	0.662	2
6/ 4	0.663	2
7/24	0.669	1
8/ 5	0.670	2
8/ 6	0.667	1
8/ 7	0.661	1
8/ 8	0.664	2
8/28	0.668	2
8/31	0.667	1
9/ 1	0.667	1
9/ 3	0.669	1
9/ 7	0.662	1
9/17	0.662	2
10/ 8	0.664	2
10/10	0.676	1
10/15	0.666	2
10/21	0.658	1
11/13	0.672	1
11/14	0.660	2
Mean	0.666	
Theoretical mean	0.667	

TABLE 3.—*Quantitative Alcohol Checks*

Date	Carbon Dioxide Produced			Oxygen Consumed			Respiratory Quotient	
	Observed, Liters	Theoretical, Liters	Difference, Percentage	Observed, Liters	Theoretical, Liters	Difference, Percentage	Observed	Theoretical
10/15/35	0.763	0.760	+0.40	1.1454	1.1400	+0.47	0.666	0.667
10/16/35	0.755	0.762	−0.92	1.1336	1.1430	−0.82	0.666	0.667
11/13/35	0.770	0.762	+1.05	1.1467	1.1430	+0.32	0.671	0.667

evident that the diameter of the spirometer is uniform. Accordingly, the value of 0.90513 liters for each rise of 1 cm. of the gasometer was used in all the computations reported in this paper.

Degree of Saturation of Air with Water Vapor: Since expired air is saturated with water vapor, a correction for the volume of water vapor is made on this basis

in computing the gaseous exchange by the usual open circuit method for the determination of basal metabolism.[76] Higgins and Bates[71] made a correction on the basis of a 100 per cent saturation for the mixture of expired air and outdoor air collected in the gasometer. In view of the fact that in the open circuit chamber method the expired air is diluted with outdoor air and that the air in Colorado is comparatively dry, it was thought advisable to determine the degree of saturation of the air in the gasometer. Fifteen determinations were made during the routine basal metabolism tests and 3 during the alcohol checks. After the desired number of samples of air for the analysis for carbon dioxide and oxygen had been collected, the gasometer was filled with air from the chamber, the volume and temperature were read and a measured amount of the air was drawn by weak suction through a series of weighed bottles containing sulfuric acid and pumice. The gain in weight of the bottles was compared with the theoretical weight of water vapor in the same volume of saturated air at the observed temperature. In no determination

TABLE 4.—*Determinations of the Vapor Pressure of the Air in the Gasometer During Basal Metabolism Tests and Alcohol Checks*

	Date, 1935	Degree of Saturation, Percentage
Metabolism test	9/27	83.0
	9/28	80.3
	9/30	84.4
	10/ 1	86.6
	10/ 2	81.3
	10/ 3	84.0
	10/ 4	84.0
	10/ 5	80.8
	10/ 8	85.7
	10/ 9	84.2
	10/10	82.6
	10/11	83.9
	10/12	88.4
	10/12	85.6
	10/14	86.5
	Mean	84.1
Alcohol checks	10/ 7	85.8
	10/10	83.8
	10/14	83.7
	Mean	84.4

did the second bottle of the series gain in weight. The values obtained are given in table 4. They vary between 80.3 and 88.4 per cent saturation, with a mean of 84 per cent. To check the method, the water vapor in the gasometer under different control conditions was determined. It was found that expired air undiluted with outdoor air gave a value of 99.6 per cent saturation and that outdoor air drawn through the chamber with no subject present gave values of from 71.8 to 78.8 per cent. If the pipes of the gasometer were wet, the values obtained were close to 100 per cent, from 96.1 to 100.3 per cent. Air passed first through the wet test meter and then into the gasometer was from 95.8 to 97 per cent saturated. Since no attempt was made during the routine determinations of basal metabolism to saturate the air, the mean value of 84 per cent saturation (table 4) has been used as a basis of correction for the determinations reported in this paper. The use of this mean introduced an error of less than 0.2 per cent on the basis of the

76. Boothby, W. M., and Sandiford, I.: Laboratory Manual of the Technic of Basal Metabolic Rate Determinations, Philadelphia, W. B. Saunders Company, 1920.

extreme variations from the mean, whereas the assumption of complete saturation would have introduced an error of approximately 0.7 per cent.

On account of the dryness of the air it has been found advisable to take special care both to keep the compensator of the gas analysis apparatus moist and to carry sufficient water on the top of the mercury to insure saturation of the air before the first reading is taken.

Technic.—Since the children being studied live in all parts of the city, it is, of course, impossible to supervise the activities of the subject on the night before an examination, but the parents are asked to see that he receives nothing to eat after the evening meal and is put to bed at the usual hour. One of the two workers in the metabolism laboratory calls for the child early in the morning, usually between 7 and 7:30, or the child is brought to the laboratory soon after rising by a member of the family. The early hour assures several desirable conditions: minimal activity during the interval between rising and arrival at the laboratory, only a slight delay before breakfast and, in the case of school children, no loss of hours at school. Because of the broadness of the program of the Child Research Council it demands much of the child's time, and objections are often raised by parents to repeated tardiness and absence of their children from school. Furthermore, many of the children are much more at ease during a test when they know that they are not to miss any time at school.

The child, dressed in his indoor clothing minus shoes, is placed in the chamber, and the cover is clamped tight after he has become relaxed and at ease. The mattress in the chamber is comfortable, and the subject experiences no discomfort. A training period is almost always necessary with inexperienced subjects, especially those in the younger age groups. A 2 year old child is able to understand what is expected of him and to cooperate intelligently if he wishes to do so. Most children, even though they are disturbed at first, readily cease crying and often become playful after they learn that they are not to be hurt in any way. The extent of the training depends on the temperament of the individual child and the cooperation of the parents. Not a small part of the success in obtaining good tests on the most difficult children of all ages can be attributed to the cooperation of the parents in permitting the child to be brought alone to the laboratory by one of the workers. This procedure is suggested if the first attempts with the parent present are wholly unsuccessful. Sometimes more effort and a longer period of training are required to keep the playful child quiet than are necessary with the naughty child.

The motor is usually started before the child enters the laboratory for the first time in order that he will not become frightened by a new and unfamiliar sound after he is in the chamber. The rate of ventilation may be adjusted immediately to that suitable for the size of the child, being left constant for the whole experimental period, or it may be cut somewhat lower than the desired final rate for from five to ten minutes at the beginning of the test to produce a more rapid building up of carbon dioxide in the chamber. The former procedure is usually followed with the smaller chambers and the latter with the large chamber. The rate of ventilation is measured by a preliminary observation of the rise of the gasometer in a timed period. It has been noted that the rate of ventilation which produces a final carbon dioxide value of from 0.40 to 0.60 per cent assures, in a large percentage of cases, a constant carbon dioxide value in the chamber after the cover has been closed for from fifteen to twenty minutes. The carbon dioxide shows a constant percentage from period to period when the rate of formation is constant, a condition which is maintained when the child is in a basal state, and the rate of removal is constant and equal to the rate of formation. The two become equal when the

carbon dioxide in the chamber reaches such a concentration that the amount removed in a given length of time is the same as the amount produced in that time. At this point the oxygen consumed is equal to the difference between the amount entering the chamber and that leaving.

One of the chief advantages of the chamber method for determining the basal metabolism of children is the complete freedom of breathing that it permits. The subject experiences no respiratory distress, and there is no cause for overventilation or underventilation of the lungs. The increase in the carbon dioxide content of the air in the chamber, to not over 0.7 volumes per cent, is not sufficient to produce detectable stimulation of the respiratory center.[77] The constancy of the respiratory quotient from period to period of a single determination is evidence that the respiration is of uniform depth. Consequently, no tracings of the respiratory movements are necessary.

One member of the staff observes the subject continuously and in the case of the younger child entertains him quietly by drawing pictures on the window with a wax pencil or by showing him small brightly colored objects and toys. It has been found that most of the smaller children and many of the larger ones are much more contented when they are entertained than when they are not. Simple objects and movements are unexciting but keep the child's attention away from himself. Entertainment also helps to relieve the boredom which may develop with the repetition of the process year after year. In the last analysis, the success of the whole procedure depends on the condition of the experimental subject, and it is felt that no effort is wasted which helps to make this condition as standard as possible. As the test progresses the worker observing the subject encourages him in all possible ways to be absolutely still. Any movements he makes are evaluated at the time and are noted on the record sheet. Some authors [1] have expressed the belief that it is necessary to obtain a graphic record of the movements to evaluate them accurately, but others [78] have found it equally or more satisfactory to estimate the degree of muscular repose at the time of the test. We feel that the latter procedure, used in this study, is very satisfactory; continuous watching of the subject is permitted, and the evaluations are made by the same workers, who have become consistent in their estimations in several years of experience. The evaluations of activity are recorded as 0, 1, 2, 3 and 4. The 0 represents an absence of noticeable movements other than those involved in respiration and in slight shifting of the eyes; 1, an occasional slight movement of the head, fingers, hands or feet; 2, movements which are similar to but more frequent than those represented by 1; 3, more gross and fairly frequent movements or continuous slight movements, and 4, continuous gross movements. Movements designated by 1 in themselves have been found to have an insignificant effect on the heat production. Tests in which there is more movement than that evaluated as 1 are not considered satisfactory and are not included with the tests classified as basal. Tests during which the subject is obviously not relaxed, has a cold, is disturbed for any reason or has gone to sleep are also excluded from the satisfactory group. Approximately 20 per cent of the tests made on the children reported on in this paper were classed as unsatisfactory and are not included in the data presented in this report.

The child is allowed to rest at least twenty minutes before the first sample of air is taken for analysis. Toward the end of the rest period the gasometer is

77. Haldane, J. S., and Priestley, J. G.: The Regulation of the Lung-Ventilation, J. Physiol. **32**:225 (May) 1905.

78. Blunt.[39] Bierring.[42]

filled with air coming from the chamber and is emptied several times by suction to wash the pipes and to obtain a constant temperature in the gasometer. Before the first sampling period a few liters of air from the chamber is allowed to pass into the gasometer. The starting point, which is now several centimeters above the zero point of the gasometer tape, is read and recorded on the data sheet, as are the final reading, the temperature and the length of the period. The capacity of the gasometer is 70 liters, and from 55 to 65 liters is collected in each sampling period. The periods vary from one to three minutes in length, depending on the size of the child. To collect air for analysis the sampler is attached at one end to the vacuum pipe and at the other end to the sampling cock of the gasometer by means of close-fitting pressure tubing. The vacuum is turned on and the sampler evacuated before the sampling cock is opened. To assure accurate sampling, from 25 to 30 liters of air is allowed to pass from the gasometer through the sampler before the stopcocks of the sampler are closed. The sampling stopcock of the gasometer is then closed, and the bell is emptied completely through the outlet pipe. A few liters of air from the chamber is allowed to pass into the gasometer, the starting point is read and a second period is begun immediately. At least four samples are taken for each test, and they are timed so that at least two are collected after the subject has been resting for thirty minutes. After the sampling is completed, the chamber is opened and the pulse and the respiration rate and the temperature of the subject are recorded. The temperature is taken rectally with the younger children and orally with the older children. The pulse and the respiration rate are not stressed, since they are not taken at the time of sampling. The subject is weighed and measured in his indoor clothing, minus shoes, and the estimated weight of the clothing is subtracted to give the recorded nude weight. The standing height is measured by means of a rigid, vertical, calibrated metal rod with a movable horizontal piece. The child stands with arms and legs collected, with heels, nates, scapulae and back of the head touching the vertical backboard of the platform. The head is held so that the lower border of the orbit and the upper border of the external meatus of the ear are on the same horizontal line, and the reading is made at the apex of the head.

At least three of the samples of gas are analyzed for carbon dioxide and at least two for oxygen. If any of the carbon dioxide and oxygen values do not check within the experimental error of the gas analysis apparatus, the analyses are repeated. The two respiratory quotients, from the results of the two complete analyses, are averaged, and the calorific value of the mean is used in the calculation of the heat production. The respiratory quotients are computed by the method given by Carpenter.[72a] A table similar to that constructed by Carpenter [79] showing the volumes of oxygen in the incoming air corresponding to 100 volumes of outgoing air for the different percentages of nitrogen has been helpful in facilitating the computation of the respiratory quotients. These volumes of oxygen depend on the values used for the carbon dioxide and the oxygen content of outdoor air, and it is suggested that such tables be constructed after a representative number of determinations of the outdoor air have been made in a definite locality.

Calculation.—The method of calculating the heat production from the carbon dioxide produced and the calorific value of a liter of carbon dioxide at the observed respiratory quotient is, in general, similar to that suggested by Higgins and Bates.[71] If the carbon dioxide content in the chamber is increasing, the

79. Carpenter, T. M.: Tables, Factors, and Formulas for Computing Respiratory Exchange and Biological Transformations of Energy, Publication 303A, Carnegie Institution of Washington, 1924.

correction for its accumulation in the chamber is made according to the method outlined by those authors. An example is given in table 5 and figure 3. In computing the volume of air in the chamber, the volumes of the mattress, the child and the pillow are subtracted from the total volume of the chamber. The

TABLE 5.—*Sample Calculation of a Test During Which the Carbon Dioxide Content of the Chamber Was Increasing*

Name, G.
Age, 5 years, 11 months
Weight, 19.1 Kg.
Height, 117.0 cm.
Temperature (F.), 98.6
Pulse rate, 84
Respiration rate, 22
Body surface (Du Bois and Du Bois [84]), 0.800

Date, 8/21/34
Barometric reading, 636.8
Vapor pressure correction (84%), 21.1
Corrected barometric reading, 615.7
Temperature of chamber (C.), 27.5
In II chamber at 8:20
Chamber closed at 8:35
Remarks: Quiet and apparently relaxed

Period	1	2	3	4	5
Activity	0	0	0	0	0
Time					
Start 8:45	0:15	3:30	6:45	11:15	15:00
End	1:45	5:00	8:15	12:45	16:30
Gasometer reading					
End	73.25	73.25	73.02	73.35	73.20
Start	26.15	26.15	26.05	26.35	26.17
Difference	47.10	47.10	46.97	47.00	47.03
Temperature (C.)	26.4	26.2	25.9	25.9	25.9
Sampler number	5	6	7	8	9
Apparatus number			2	1	1
CO_2			0.558	0.574	0.585
O_2			.....	20.304	20.294
Respiratory quotient			.....	0.821	0.825
					Average, 0.823

Log gas. factor	9.95671–10	Liters CO_2/hr. (S.T.P.)‡	7.068
Log gas. difference	1.67210	Liters O_2/hr. (S.T.P.)	8.588
Log CO_2 gain	7.73560–10	Log l. CO_2/hr. (S.T.P.)	0.84928
Log CO_2 (l.)	9.36441–10	Log CO_2 cal. value	0.76388
		Log cal./hr.	1.61316
Volume box (l.)	176.8	Calories/hr.	41.0
Volume child (l.) + pillow	29.7	Log cal./hr.	1.61316
Volume air (l.)	147.1	Colog surface	0.09691
CO_2 at end (l.)	0.005762	Log cal./hr./sq.m.	1.71007
CO_2 at beginning (l.)	0.005712	Cal./hr./sq.m.	51.3
CO_2 change (l.)	0.00005	Log cal./hr.	1.61316
Residual CO_2 (l.)*	0.00736	Colog Kg.	8.71897–10
CO_2 in gasometer (l.)	0.23144	Log cal./hr./Kg.	0.33213
Total CO_2 (l.)	0.23880	Cal./hr./Kg.	2.15
Time (minutes) 1.5		Log cal./hr.	1.61316
CO_2 per minute (l.)	0.15920	Colog cm.	7.93181–10
		Log cal./hr./cm.	9.54497–10
Log l. CO_2/min.	9.20194–10	Cal./hr./cm.	0.351
Log constant †	1.33350		
Log P (corrected)	2.78937		
Colog T	7.52447–10		
Log l. CO_2/hr. (S.T.P.)	0.84928		
Colog R. Q.	0.08460		
Log l. O_2/hr.	0.93388		

* Increase in CO_2 in chamber during sampling period.

† Constant $= \frac{273 \times 60}{760}$

‡ S.T.P. indicates standard temperature and pressure.

numerical value of the child's uncorrected weight in kilograms is taken as the volume of the child in liters, since the specific gravity of the human body is close to unity. The values given by Boyd [80] for the maximum range in observed specific gravity, regardless of the respiratory phase or age, are from 0.940 to

80. Boyd, E.: The Growth of the Surface Area of the Human Body, Minneapolis, University of Minnesota Press, 1935.

1.092. Zook [81] reported that the specific gravity of boys increases with age from approximately 1 at 5 years to about 1.04 at 19 years. If the specific gravity of children between the ages of 2 and 12 years, inclusive, is calculated by means of the regression equation given by Boyd [80] for quiet respiration ($G = 1.016 + 0.0010 A$, G equaling the specific gravity and A the age in years), the values obtained vary only slightly from unity (table 6). Thus the use of unity as the specific

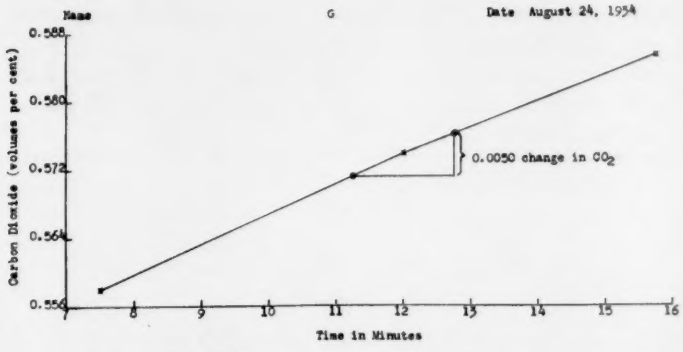

Fig. 3.—Curve of the carbon dioxide change in the chamber during the test of which a sample calculation is given in table 5. The points plotted (×) mark the middle of each period and the amount of carbon dioxide (volumes per cent) collected in that period. The residual carbon dioxide (volumes per cent) accumulated in the chamber during the middle period was determined by reading the difference between the carbon dioxide value (°) on the curve at the beginning and that at the end of that period.

TABLE 6.—*Specific Gravity of Children Between the Ages of 2 and 12 Years, Inclusive, During Quiet Respiration (From Boyd [80])*

Age, Years	Specific Gravity
2	1.018
3	1.019
4	1.020
5	1.021
6	1.022
7	1.023
8	1.024
9	1.025
10	1.026
11	1.027
12	1.028

gravity of the child introduces the insignificant error of less than 0.02 calory per hour in the case of maximum error.

In determinations of basal metabolism in which equilibrium is established before the samples are collected, as evidenced by constant values for carbon dioxide and oxygen from period to period, the computation of the heat production is somewhat simpler, since the correction for the accumulation of carbon dioxide in the chamber is eliminated. A sample calculation of this type is given in table 7. In only 12 per cent of the 637 determinations reported in this paper was equilibrium not

81. Zook, D. E.: The Physical Growth of Boys: A Study by Means of Water Displacement, Am. J. Dis. Child. **43**:1347 (May) 1932.

established before the collection of the last three samples, and these instances occurred principally in the early part of the study.

It is believed that the single specimen of urine which it is possible to collect is valueless for determining the protein metabolism; consequently, no determination

TABLE 7.—*Sample Calculation of a Test in Which the Carbon Dioxide Content of the Chamber Was Constant*

No. 74 (2)
Age, 3 years, 8 months
Weight, 16.6 Kg.
Height, 106.0 cm.
Temperature (F.), 99.0 R.
Pulse rate, 86
Respiration rate, 26
Body surface (Du Bois and Du Bois [84]), 0.695

Date, 1/13/36
Barometric reading, 625.1
Vapor pressure correction (84%), 20.0
Corrected barometric reading, 605.1
Temperature of chamber (C.), 26.6
In II chamber at 7:30
Chamber closed at 7:33
Comment: Quiet and apparently relaxed; entertained

Period	1	2	3	4
Activity	0	0	0	0
Time				
Start 7:55	0:15	4:00	7:45	11:30
End	1:45	5:30	9:15	13:00
Gasometer reading				
End	63.50	63.50	63.50	63.50
Start	10.05	10.10	10.05	10.08
Difference	53.45	53.40	53.45	53.42
Temperature (C.)	25.5	25.0	25.0	25.0
Sampler number	1	2	3	4
Apparatus number		1	2	1
CO_2		0.468	0.465	0.466
O_2		20.427	20.425	
Respiratory quotient		0.817	0.807	
				Average, 0.812

Log gas. factor	9.95671–10	Liters CO^2/hr. (S.T.P.)‡	6.151
Log gas. difference	1.72770	Liters O_2/hr. (S.T.P.)	7.575
Log CO_2 gain	7.63949–10	Log l. CO_2/hr. (S.T.P.)	0.78892
Log CO^2 (l.)	9.32390–10	Log CO_2 cal. value	0.76849
		Log cal./hr.	1.55741
Volume box (l.)		Calories/hr.	36.1
Volume child (l.)		Log cal./hr.	1.55741
Volume air (l.)		Colog surface	0.15802
CO_2 at end (l.)		Log cal./hr./sq.m.	1.71543
CO_2 at beginning (l.)		Cal./hr./sq m	51.9
CO_2 change (l.)		Log cal./hr.	1.55741
Residual CO_2 (l.)*		Colog Kg	8.77989–10
CO_2 in gasometer (l.)		Log cal./hr./Kg	0.33730
Total CO_2 (l.)		Cal./hr./Kg	2.17
Time (minutes) 1.5 (colog)	9.82391–10	Log cal./hr.	1.55741
CO_2 per minute (l.)		Colog cm	7.97469–10
		Log cal./hr./cm	9.52310–10
Log l. CO_2/min	9.14781–10	Cal./hr./cm	0.340
Log. constant †	1.33350		
Log P (corrected)	2.78183		
Colog T	7.52578–10		
Log l. CO_2/hr. (S.T.P.)	0.78892		
Colog R. Q	0.09044		
Log l. O_2/hr	0.87936		

* Increase in CO_2 in chamber during sampling period.

† Constant $= \frac{273 \times 60}{760}$

‡ S.T.P. indicates standard temperature and pressure.

of the urinary nitrogen is made. Magnus-Levy and Falk [7] stated that from 12 to 18 per cent of the total calories are derived from protein after a fast of from twelve to fourteen hours, and they constructed a table of calorific values for oxygen based on the assumption that an average of 15 per cent of the calories are derived from the oxidation of protein. Du Bois [82] suggested that in cases of

82. Du Bois, E. F.: Basal Metabolism in Health and Disease, Philadelphia, Lea & Febiger, 1927.

which the protein metabolism is not measured it be assumed that 15 per cent of the heat production was derived from the oxidation of protein. The suggestion was followed in our study. The calorific values of a liter of oxygen for the various respiratory quotients were obtained from the chart constructed by Michaelis [83] in 1924. These values and the corresponding values for a liter of carbon dioxide are given in table 8. The calorific values agree closely with those reported by Magnus-Levy and Falk [7] (table 9). The value for the carbon dioxide given off, in combination with the respiratory quotient observed, was used as the basis for computation of the heat production.

The body surface values were obtained from the nomograms constructed from the Du Bois and Du Bois [84] height-weight formula by Boothby and Sandiford [85] for the larger children and by Hannon [85a] for the smaller children. Concerning the accuracy of the Du Bois and Du Bois height-weight formula, Boyd [80] reported that it predicted the body surface of 197 subjects with a standard deviation of the calculated from the measured value of 7.2 ± 0.4 per cent, which deviation is not significantly larger than the predicted value of the new surface-weight-height equation of Boyd. The latter equation is a self-adjusting power equation and is reported by Boyd to be the best single equation for the prediction of the body surface from other dimensions of the body. Its prediction value is 7.1 ± 0.3 per cent.

EXPERIMENTAL RESULTS

Tables 10 and 11 contain the satisfactory results obtained before April 1, 1936, on each subject. The data are given in detail in order that recalculations or new interpretations may easily be made from them. The age of the child was computed on the basis of the completed year and month, i. e., the age of a child who was born on June 6, 1930, was 4 years and 10 months during the interval between April 6 and May 5, 1935, inclusive. The birthday of each subject was included rather than the date of each test. Tests in which there was any question of faulty technic were discarded entirely, and those in which there was evidence of activity, drowsiness, a cold or a low degree of relaxation were not reported. Numbers designate children who have been observed from birth and letters members of the special series. The data represent 271 satisfactory tests on 41 girls and 366 satisfactory tests on 52 boys, all the children being between the ages of 2 and 12 years, inclusive.

The results can be studied from two standpoints, the longitudinal and the cross-sectional. It is not the purpose of this paper to present

83. Michaelis, A. M.: Clinical Calorimetry: XXXVI. A Graphic Method of Determining Certain Numerical Factors in Metabolism, J. Biol. Chem. **59**:51 (Feb.) 1924.

84. Du Bois, D., and Du Bois, E. F.: Clinical Calorimetry: X. A Formula to Estimate the Approximate Surface Area if Height and Weight Be Known, Arch. Int. Med. **17**:863 (June) 1916.

85. Boothby, W. M., and Sandiford, R. B.: Nomographic Charts for the Calculation of the Metabolic Rate by the Gasometer Method, Boston M. & S. J. **185**:337 (Sept. 22) 1921.

85a. Hannon, cited by du Bois.[82]

TABLE 8.—*Calorific Values for Oxygen and Carbon Dioxide (15 per Cent of Total Calories Derived from Protein Metabolism)*

Observed Respiratory Quotient	Caloric Equivalent of 1 Liter of Oxygen*	Caloric Equivalent of 1 Liter of Carbon Dioxide†	Observed Respiratory Quotient	Caloric Equivalent of 1 Liter of Oxygen*	Caloric Equivalent of 1 Liter of Carbon Dioxide†
0.760	4.700	6.184	0.841	4.801	5.709
0.761	4.701	6.178	0.842	4.802	5.703
0.762	4.702	6.171	0.843	4.803	5.698
0.763	4.704	6.165	0.844	4.805	5.693
0.764	4.705	6.158	0.845	4.806	5.688
0.765	4.706	6.152	0.846	4.807	5.682
0.766	4.708	6.146	0.847	4.808	5.677
0.767	4.709	6.139	0.848	4.810	5.672
0.768	4.710	6.133	0.849	4.811	5.666
0.769	4.711	6.126	0.850	4.812	5.661
0.770	4.712	6.120	0.851	4.813	5.656
0.771	4.714	6.114	0.852	4.815	5.651
0.772	4.715	6.108	0.853	4.816	5.646
0.773	4.716	6.101	0.854	4.817	5.641
0.774	4.718	6.095	0.855	4.819	5.636
0.775	4.719	6.089	0.856	4.820	5.631
0.776	4.720	6.083	0.857	4.821	5.626
0.777	4.722	6.077	0.858	4.823	5.621
0.778	4.723	6.070	0.859	4.824	5.616
0.779	4.724	6.064	0.860	4.825	5.611
0.780	4.725	6.058	0.861	4.827	5.606
0.781	4.727	6.052	0.862	4.828	5.601
0.782	4.728	6.046	0.863	4.829	5.596
0.783	4.729	6.039	0.864	4.831	5.591
0.784	4.730	6.033	0.865	4.832	5.586
0.785	4.731	6.027	0.866	4.833	5.580
0.786	4.733	6.021	0.867	4.834	5.575
0.787	4.734	6.015	0.868	4.835	5.570
0.788	4.735	6.008	0.869	4.836	5.565
0.789	4.736	6.002	0.870	4.837	5.560
0.790	4.737	5.996	0.871	4.838	5.555
0.791	4.738	5.990	0.872	4.840	5.550
0.792	4.739	5.984	0.873	4.841	5.545
0.793	4.741	5.978	0.874	4.842	5.540
0.794	4.742	5.972	0.875	4.844	5.536
0.795	4.744	5.967	0.876	4.845	5.531
0.796	4.745	5.961	0.877	4.846	5.526
0.797	4.746	5.955	0.878	4.847	5.521
0.798	4.747	5.949	0.879	4.849	5.516
0.799	5.748	5.943	0.880	4.850	5.511
0.800	4.750	5.937	0.881	4.851	5.506
0.801	4.751	5.931	0.882	4.852	5.501
0.802	4.752	5.925	9.883	4.854	5.497
0.803	4.754	5.920	0.884	4.855	5.492
0.804	4.755	5.914	0.885	4.856	5.487
0.805	4.756	5.908	0.886	4.857	5.482
0.806	4.757	5.902	0.887	4.858	5.477
0.807	4.758	5.896	0.888	4.860	5.473
0.808	4.760	5.891	0.889	4.861	5.468
0.809	4.761	5.885	0.890	4.862	5.463
0.810	4.762	5.879	0.891	4.863	5.458
0.811	4.763	5.873	0.892	4.865	5.454
0.812	4.765	5.868	0.893	4.866	5.449
0.813	4.766	5.862	0.894	4.868	5.445
0.814	4.768	5.857	0.895	4.869	5.440
9.815	4.769	5.851	0.896	4.870	5.435
0.816	5.770	5.845	0.897	4.872	5.431
0.817	4.771	5.840	0.898	4.873	5.426
0.818	4.772	5.834	0.899	4.874	5.422
0.819	4.773	5.828	0.900	4.875	5.417
0.820	4.775	5.823	0.901	4.876	5.412
0.821	4.776	5.817	0.902	4.878	5.408
0.822	4.777	5.812	0.903	4.879	5.403
0.823	4.778	5.806	0.904	4.880	5.398
0.824	4.780	5.801	0.905	4.881	5.394
0.825	4.781	5.795	0.906	4.882	5.389
0.826	4.782	5.789	0.907	4.883	5.384
0.827	4.783	5.784	0.908	4.884	5.379
0.828	4.784	5.778	0.909	4.886	5.375
0.829	4.786	5.773	0.910	4.887	5.370
0.830	4.787	5.767	0.911	4.888	5.366
0.831	4.788	5.762	0.912	4.889	5.361
0.832	4.789	5.756	0.913	4.891	5.357
0.833	4.791	5.751	0.914	4.892	5.352
0.834	4.792	5.746	0.915	4.893	5.348
0.835	4.794	5.741	0.916	4.895	5.344
0.836	4.795	5.736	0.917	4.896	5.339
0.837	4.796	5.730	0.918	4.898	5.335
0.838	4.798	5.725	0.919	4.899	5.330
0.839	4.799	5.719	0.920	4.900	5.326
0.840	4.800	5.714			

* The caloric values for oxygen were obtained from the triangle of Michaelis.[83]

† The caloric values for carbon dioxide were calculated by dividing the caloric values for oxygen by the corresponding respiratory quotient.

the data from the former point of view, since it is felt that this can be done most effectively by also presenting other physiologic measurements made on the same child at the same time and over as long a period of observation as possible. Obviously, such a correlated study cannot be made at the present stage of the work. By the cross-sectional method each child is considered a new subject with each test, and the data on all the subjects are treated in convenient arbitrary groupings. The motive of such a treatment is to determine the range of normal variation, the mean value and the general trend and to establish normal standards from the statistics thus obtained. Cross-sectional handling of the results is presented in the following paragraphs.

The data for boys and girls were grouped separately according to age, weight, height and body surface. The mean, the standard deviation from the mean and the coefficient of variation of the calories per hour in relation to age, weight, height and body surface, respectively,

TABLE 9.—*Calorific Values of Oxygen from Magnus-Levy and Falk*[7] *(15 per Cent of Total Calories Derived from Protein Metabolism)*

Observed Respiratory Quotient	Caloric Equivalent of 1 Liter of Oxygen
0.720	4.654
0.756	4.700
0.799	4.752
0.825	4.785
0.842	4.805
0.884	4.857
0.937	4.909
0.969	4.961

and of calories per hour per square meter, calories per hour per kilogram and calories per hour per centimeter, respectively, in relation to age, were computed. The standard error of the mean and the standard error of the standard deviation were also calculated. The formulas used in the computation of the statistics are as follows:

$$\text{Mean } (m) = \frac{\Sigma x}{n}$$

$$\text{Standard deviation } (\delta) = \sqrt{\frac{\Sigma x^2}{n} - m^2}$$

$$\text{Coefficient of variation} = \frac{\delta\,(100)}{m}$$

$$\text{Standard error of the mean} = \frac{\delta}{\sqrt{n-1}}$$

$$\text{Standard error of the standard deviation} = \frac{\delta}{\sqrt{2\,(n-1)}}$$

The letter n denotes the number of tests; x, the value of any single test, and Σ, the sum.

It may be well to stress here the fact that the value of statistical treatment of the amount of data reported in this paper is limited. How-

TABLE 10.—*Data of Individual Basal Metabolism Tests on Boys*

Subject, Sex, Date of Birth	Age Yr.	Age Mo.	Pulse Rate	Respiration Rate	Temperature, F.	Weight, Kg.	Height, Cm.	Body Surface, Sq. M.	Oxygen Consumed, L. per Hr.	Carbon Dioxide Produced, L. per Hr.	Respiratory Quotient	Cal./Hr.	Cal./Hr./Sq. M.	Cal./Hr./Kg.	Cal./Hr./Cm.
28	2	0	104	30	98.8 R	12.0	86.9	0.525	6.006	4.918	0.819	28.7	54.6	2.39	0.330
M	2	3	108	32	99.5 R	12.2	89.1	0.540	6.567	5.175	0.788	31.1	57.6	2.55	0.349
10/28/32	2	9	90	27	99.0 R	13.6	93.6	0.585	6.717	5.588	0.832	32.2	55.0	2.37	0.344
	3	3	92	26	99.4 R	14.7	96.5	0.615	6.862	5.764	0.840	32.9	53.6	2.24	0.341
4	2	2	80	..	99.0 R	14.2	89.5	0.575	6.434	5.630	0.875	31.2	54.2	2.19	0.348
M	2	10	78	..	98.6 R	15.4	94.6	0.630	6.594	5.790	0.878	32.0	50.7	2.08	0.338
5/3/30	3	1	80	..	98.5 R	16.1	96.7	0.645	6.758	5.697	0.843	32.5	50.3	2.02	0.336
	3	4	84	..	98.7 R	16.7	99.7	0.670	6.858	5.761	0.840	32.9	49.1	1.97	0.330
	3	7	80	..	98.4 R	17.2	101.6	0.685	7.308	6.310	0.864	35.3	51.5	2.05	0.347
	3	10	76	..	98.6 R	17.7	103.0	0.700	7.306	6.166	0.844	35.1	50.1	1.98	0.341
	4	2	76	23	98.6	17.7	106.2	0.715	7.765	6.562	0.845	37.3	52.2	2.11	0.351
	4	4	68	20	98.6	18.7	107.4	0.740	7.584	6.500	0.857	36.6	49.4	1.96	0.340
	4	9	66	22	98.7	19.3	110.5	0.765	7.513	6.574	0.875	36.4	47.6	1.89	0.329
	5	3	67	24	98.4	20.0	113.6	0.800	8.076	6.897	0.854	38.9	48.6	1.95	0.342
	5	8	66	22	98.6	21.1	117.0	0.825	8.313	7.116	0.856	40.1	48.6	1.90	0.342
23	2	2	96	..	98.8 R	12.9	89.0	0.550	6.089	4.993	0.820	29.1	52.9	2.25	0.327
M	2	5	90	..	98.4 R	13.2	90.5	0.565	5.891	5.107	0.867	28.5	50.4	2.16	0.315
8/31/30	2	8	96	..	98.8 R	13.5	92.2	0.580	5.957	4.741	0.796	28.3	48.7	2.09	0.307
	3	3	90	..	98.0 R	14.7	96.3	0.615	6.451	5.180	0.803	30.7	49.9	2.09	0.318
	3	6	90	..	98.4 R	15.4	96.7	0.635	6.364	5.352	0.841	30.6	48.1	1.98	0.316
	3	11	86	28	98.6 R	15.9	100.0	0.660	6.884	5.789	0.841	33.1	50.1	2.08	0.331
	4	3	88	24	98.6 R	16.7	101.9	0.680	6.792	5.759	0.848	32.7	48.0	1.96	0.321
	4	7	90	23	98.3 R	17.6	104.9	0.710	7.220	6.195	0.858	34.8	49.0	1.98	0.332
	5	1	83	22	98.6 R	18.6	107.8	0.735	7.575	6.287	0.830	36.3	49.3	1.95	0.336
	5	5	84	24	98.8 R	19.7	110.9	0.770	7.711	6.477	0.840	37.0	48.1	1.88	0.334
19	2	3	87	28	99.0 R	14.4	92.7	0.590	6.614	5.562	0.841	31.8	53.8	2.21	0.343
M	3	1	86	26	98.6 R	16.7	99.4	0.670	6.910	6.005	0.869	33.4	49.9	2.00	0.336
8/11/32	3	5	72	25	99.0 R	17.2	101.8	0.685	7.502	6.564	0.875	36.3	53.0	2.11	0.357
49, M	2	5	106	27	99.2 R	12.2	91.5	0.550	6.362	5.344	0.840	30.5	55.5	2.50	0.334
7/12/33	2	8	102	28	99.4 R	12.6	93.9	0.565	6.871	5.476	0.797	32.6	57.7	2.59	0.347
74	2	5	88	24	98.6 R	14.4	95.9	0.615	6.563	5.473	0.834	31.4	51.1	2.18	0.328
M	2	9	91	24	98.7 R	15.4	98.5	0.645	6.714	5.714	0.851	32.3	50.1	2.10	0.328
4/19/32	3	8	86	26	99.0	16.6	106.0	0.695	7.575	6.151	0.812	36.1	51.9	2.17	0.340
16	2	5	100	25	98.9 R	13.4	91.1	0.570	6.688	5.324	0.796	31.7	55.7	2.37	0.348
M	2	9	100	22	98.8 R	14.5	94.5	0.605	7.312	5.608	0.767	34.4	56.9	2.37	0.364
7/31/32	3	3	96	22	98.6 R	15.5	98.4	0.645	7.251	6.200	0.855	34.9	54.2	2.25	0.355
	3	7	92	26	98.8 R	16.0	100.6	0.660	7.469	6.065	0.812	35.6	53.9	2.22	0.354
27	2	6	120	..	99.2 R	13.2	92.4	0.570	6.405	5.329	0.832	30.7	53.8	2.32	0.332
M	3	10	92	24	98.0	16.3	103.1	0.680	7.871	6.391	0.812	37.5	55.1	2.30	0.364
11/7/30	4	6	78	20	98.2	17.9	108.7	0.730	7.566	6.288	0.831	36.2	49.6	2.02	0.333
	5	1	84	22	99.0	18.8	112.4	0.765	8.362	6.740	0.806	39.8	52.0	2.12	0.354

51	2	6	98	23	99.2 R	14.4	96.4	0.615	7.028	5.932	0.844	33.8	54.9	2.35	0.350
M	2	9	104	21	98.6 R	15.3	98.4	0.645	7.299	6.145	0.842	35.0	54.3	2.29	0.356
1/21/32	3	1	102	28	98.6 R	16.7	101.4	0.675	7.081	6.075	0.858	34.1	50.6	2.04	0.337
	3	8	88	23	98.4 R	17.3	105.7	0.705	7.603	6.394	0.841	36.5	51.8	2.11	0.345
	4	1	86	24	98.6	18.7	109.8	0.750	7.835	6.495	0.829	37.5	50.0	2.01	0.341
35	2	6	100	..	99.0 R	15.2	92.2	0.605	7.379	6.095	0.826	35.3	58.3	2.32	0.383
M	2	11	96	..	98.3	16.4	94.8	0.640	6.708	5.768	0.860	32.4	50.6	1.97	0.341
3/14/31	3	4	96	..	99.0	16.3	97.0	0.650	8.022	6.827	0.851	38.6	59.4	2.37	0.398
	3	7	96	28	99.4	17.0	99.4	0.670	7.682	6.576	0.856	37.0	55.3	2.18	0.37[illegible]
	4	0	96	29	98.2	17.7	102.6	0.695	7.878	6.830	0.867	38.1	54.8	2.15	0.371
	4	6	92	24	98.6	18.6	105.4	0.725	7.951	6.798	0.855	38.3	52.8	2.06	0.363
	4	10	88	23	98.7	19.2	107.5	0.750	8.739	7.341	0.840	41.9	55.9	2.18	0.390
55	2	6	82	..	98.6 R	13.6	92.5	0.580	6.519	5.196	0.797	30.9	53.3	2.28	0.334
M	3	1	92	26	98.6 R	14.7	97.3	0.625	7.094	6.009	0.847	34.1	54.6	2.32	0.351
1/16/32	3	6	84	28	98.4 R	16.7	100.3	0.670	7.673	6.883	0.897	37.4	55.8	2.24	0.373
	3	10	90	24	98.8 R	16.3	103.3	0.680	8.041	6.843	0.851	38.7	56.9	2.37	0.375
	4	2	84	24	98.6 R	17.6	105.8	0.710	7.685	6.686	0.870	37.2	52.4	2.11	0.351
75	2	7	98	23	99.0 R	12.9	94.0	0.575	6.174	5.408	0.876	29.9	52.0	2.32	0.318
M	2	11	100	..	99.4 R	13.7	96.4	0.600	6.887	5.668	0.823	32.9	54.8	2.40	0.341
4/24/32	3	10	82	22	99.0 R	15.8	102.2	0.665	7.483	6.376	0.852	36.0	54.2	2.28	0.353
29	2	7	108	..	99.1 R	13.6	88.8	0.565	6.935	5.790	0.835	33.2	58.8	2.44	0.374
M	2	10	102	..	98.9 R	14.0	91.4	0.580	7.033	6.252	0.889	34.2	58.9	2.44	0.374
3/7/31	3	6	88	26	98.6 R	15.0	96.5	0.630	7.140	5.962	0.835	34.2	54.3	2.28	0.355
	3	11	97	24	99.0 R	15.8	99.8	0.655	7.322	6.355	0.868	35.4	54.0	2.24	0.355
	4	6	98	21	98.7	16.8	104.5	0.695	7.909	6.809	0.861	38.2	54.9	2.27	0.365
	4	10	90	20	98.6	17.8	107.2	0.720	8.109	6.982	0.861	39.1	54.4	2.20	0.365
96, M	2	7	92	26	98.4 R	14.3	93.3	0.600	6.131	5.218	0.851	29.5	49.2	2.06	0.316
9/13/32	3	0	98	26	98.8 R	15.5	96.0	0.635	7.012	5.715	0.815	33.4	52.7	2.16	0.348
62	2	9	116	..	99.3 R	12.8	95.6	0.580	6.927	5.659	0.817	33.0	57.0	2.58	0.346
M	3	4	104	28	98.8 R	14.2	100.4	0.630	7.494	6.280	0.838	36.0	57.1	2.53	0.358
1/9/32	3	9	96	28	99.0 R	15.4	104.1	0.670	8.032	6.683	0.832	38.5	57.4	2.50	0.370
	4	2	90	24	99.0 R	16.1	106.3	0.690	8.254	6.710	0.813	39.3	57.0	2.44	0.370
63, M	2	10	78	22	99.2 R	15.5	97.0	0.635	7.302	6.382	0.874	35.4	55.7	2.28	0.365
4/20/33															
52, M	2	10	104	20	99.0 R	14.1	98.1	0.615	6.512	5.236	0.804	31.0	50.4	2.20	0.316
9/18/32															
25	3	0	94	..	99.6 R	14.6	95.7	0.610	6.293	5.405	0.859	30.4	49.8	2.08	0.317
M	3	8	82	27	98.6 R	16.4	101.6	0.670	7.659	6.663	0.870	37.0	55.3	2.26	0.365
12/1/30	4	0	82	22	98.5 R	17.2	104.1	0.695	7.669	6.342	0.827	36.7	52.8	2.13	0.352
	4	10	84	27	98.6 R	19.7	110.8	0.775	8.169	6.846	0.838	39.2	50.6	1.99	0.354
	5	2	72	24	98.2 R	20.2	114.0	0.800	8.555	7.143	0.835	41.0	51.3	2.03	0.360
92	3	0	90	..	98.5	17.1	100.3	0.680	7.397	5.969	0.807	35.2	51.8	2.06	0.351
M	3	3	96	..	98.4	17.5	101.6	0.690	7.053	6.080	0.862	34.1	49.3	1.95	0.335
2/16/29	3	7	80	..	98.2	18.3	105.5	0.720	6.857	5.684	0.829	32.8	45.6	1.79	0.311
	3	10	72	..	98.6	19.4	107.3	0.750	8.183	7.021	0.858	39.5	52.6	2.03	0.368
	4	0	78	..	99.2	18.9	109.6	0.750	7.172	6.246	0.871	34.7	46.3	1.84	0.317
	4	4	82	..	98.2	19.4	110.5	0.770	8.222	6.964	0.847	39.5	51.3	2.04	0.358
	4	6	78	..	97.8	19.4	113.0	0.780	7.808	6.660	0.853	37.6	48.2	1.94	0.333
	4	10	72	..	98.1	20.0	113.7	0.795	7.782	6.669	0.857	37.5	47.2	1.88	0.330

TABLE 10.—*Data of Individual Basal Metabolism Tests on Boys—Continued*

Subject, Sex, Date of Birth	Age Yr.	Age Mo.	Pulse Rate	Respiration Rate	Temperature, F.	Weight, Kg.	Height, Cm.	Body Surface, Sq. M.	Oxygen Consumed, L. per Hr.	Carbon Dioxide Produced, L. per Hr.	Respiratory Quotient	Cal./Hr.	Cal./Hr./Sq. M.	Cal./Hr./Kg.	Cal./Hr./Cm.
92 (cont.)	5	1	80	..	98.3	21.3	115.1	0.825	8.882	7.026	0.791	42.1	51.0	1.98	0.366
	5	5	78	24	98.4	21.0	117.6	0.830	8.107	6.786	0.837	38.9	46.8	1.85	0.331
	5	9	75	20	98.1	23.4	119.6	0.880	8.586	7.358	0.857	41.4	47.0	1.77	0.346
	6	0	75	22	98.6	23.6	122.4	0.895	8.384	7.352	0.877	40.6	45.4	1.72	0.332
	6	5	70	20	97.8	24.0	125.3	0.920	8.858	7.556	0.853	42.7	46.4	1.78	0.340
	6	11	72	24	98.4	26.2	128.8	0.970	9.735	8.060	0.830	46.6	48.0	1.78	0.362
93	3	2	78	..	98.4	14.8	99.1	0.630	6.941	5.928	0.854	33.4	53.1	2.26	0.337
M	3	10	84	..	98.0	16.5	105.4	0.690	7.615	6.168	0.810	36.3	52.6	2.20	0.344
3/31/29	4	4	92	..	98.4	17.2	111.1	0.730	7.985	6.643	0.832	38.2	52.4	2.22	0.344
	4	7	80	..	98.8	17.6	111.8	0.740	8.010	6.736	0.841	38.5	52.0	2.19	0.344
	4	11	80	..	99.0	17.8	112.4	0.750	8.132	7.116	0.875	39.4	52.5	2.21	0.350
	5	2	84	20	98.6	18.6	114.4	0.775	8.332	6.716	0.806	39.6	51.1	2.13	0.346
	5	5	77	20	98.4	19.5	115.8	0.800	8.158	6.869	0.842	39.2	49.0	2.01	0.338
	5	9	82	20	98.4	20.2	117.4	0.820	8.819	7.576	0.859	42.5	51.9	2.11	0.362
	6	0	85	18	98.2	21.0	118.4	0.835	8.486	6.993	0.824	40.6	48.6	1.93	0.343
	6	5	70	18	98.6	21.5	121.0	0.850	8.619	7.456	0.865	41.6	49.0	1.94	0.344
	6	9	71	17	98.4	22.6	123.4	0.885	8.800	7.525	0.855	42.4	47.9	1.88	0.344
D. G., M	3	4	101	28	99.2 R	15.6	99.0	0.650	7.175	6.192	0.863	34.7	53.3	2.22	0.350
1/11/32	3	11	80	24	98.8 R	16.6	103.8	0.685	7.576	6.508	0.859	36.5	53.4	2.20	0.352
5	4	0	110	30	99.0 R	16.8	109.3	0.715	7.525	6.306	0.838	36.1	50.5	2.15	0.330
M	4	3	84	28	....	17.7	110.2	0.735	7.606	6.609	0.869	36.8	50.0	2.08	0.334
6/6/30	4	8	92	26	98.8 R	18.7	112.2	0.765	7.910	6.463	0.817	37.7	49.3	2.02	0.336
	5	2	82	24	98.4 R	18.7	115.7	0.785	7.292	6.293	0.863	35.2	44.9	1.88	0.304
	5	7	88	24	98.8 R	20.1	117.7	0.815	8.323	7.050	0.847	40.0	49.1	1.99	0.340
88	4	1	80	..	99.0	19.5	104.7	0.740	8.221	7.103	0.864	39.7	53.7	2.04	0.379
M	5	3	80	..	98.4	20.6	113.7	0.810	9.395	7.864	0.837	45.1	55.6	2.19	0.396
9/23/28	5	6	76	..	98.8	21.3	114.8	0.820	8.880	7.841	0.883	43.1	52.6	2.02	0.375
	6	1	76	18	98.4	22.6	118.2	0.860	9.195	7.742	0.842	44.2	51.3	1.95	0.374
G.	4	3	88	..	98.6	17.1	105.4	0.700	7.867	6.805	0.865	38.0	54.3	2.22	0.361
M	4	6	92	..	97.9	16.1	106.7	0.690	7.806	6.596	0.845	37.5	54.4	2.33	0.352
8/30/28	5	1	78	..	98.6	18.1	111.1	0.745	8.496	7.120	0.838	40.8	54.7	2.25	0.367
	5	5	78	..	99.0	18.5	113.3	0.765	8.973	7.493	0.835	43.0	56.2	2.33	0.380
	5	8	78	..	98.4	18.6	115.1	0.780	9.004	7.401	0.822	43.0	55.1	2.31	0.374
	5	11	84	22	98.6	19.1	117.0	0.800	8.588	7.068	0.823	41.0	51.3	2.15	0.351
	6	7	85	21	98.6	21.0	120.3	0.840	8.206	7.237	0.882	39.8	47.4	1.90	0.331
	7	1	89	21	98.6	21.8	123.8	0.870	8.895	7.258	0.816	42.4	48.8	1.95	0.343
	7	5	78	22	98.6	22.6	125.2	0.895	9.311	7.561	0.812	44.4	49.6	1.96	0.354
81	4	3	86	..	....	16.3	104.1	0.680	7.626	6.177	0.810	36.3	53.4	2.23	0.349
M	4	6	90	..	98.6	17.4	104.1	0.700	7.635	5.949	0.779	36.1	51.5	2.07	0.346
10/19/27	4	9	78	..	98.2	16.9	107.3	0.710	7.564	6.150	0.813	36.1	50.8	2.14	0.336

81	4	3	86	..	....	16.3	104.1	0.680	7.626	6.177	0.810	36.3	53.4	2.23	0.349
M	4	6	90	..	98.6	17.4	104.1	0.700	7.635	5.949	0.779	36.1	51.5	2.07	0.346
10/19/27	4	9	78	..	98.2	16.9	107.3	0.710	7.564	6.150	0.813	36.1	50.8	2.13	0.336
	5	0	80	..	98.6	18.0	109.2	0.735	7.611	6.751	0.887	37.0	50.3	2.05	0.339
	5	0	78	..	98.6	18.0	109.2	0.735	7.563	6.187	0.818	36.1	49.1	2.01	0.331
	5	0	74	..	99.0	18.1	109.2	0.740	7.859	6.610	0.841	37.7	51.0	2.08	0.346
	5	0	82	..	99.2	18.1	109.2	0.740	7.733	6.697	0.866	37.4	50.5	2.06	0.342
	5	1	78	..	99.0	18.1	109.2	0.740	7.772	6.653	0.856	37.5	50.6	2.07	0.343
	5	3	84	..	98.4	18.2	110.5	0.745	8.441	6.972	0.826	40.4	54.2	2.22	0.365
	5	6	80	..	98.4	18.1	111.8	0.750	8.138	6.616	0.813	38.8	51.7	2.14	0.347
	5	10	82	..	98.4	18.8	114.3	0.780	8.373	7.000	0.836	40.2	51.5	2.14	0.351
	6	5	84	..	98.6	19.6	117.5	0.810	8.613	7.158	0.831	41.2	50.9	2.10	0.351
	6	10	84	18	98.6	19.7	119.0	0.820	8.435	7.473	0.886	41.0	50.0	2.08	0.344
	7	1	..	19	....	20.9	121.4	0.845	8.470	7.115	0.840	40.7	48.1	1.95	0.335
	7	5	84	18	98.4	22.5	122.8	0.880	8.681	7.440	0.857	41.9	47.6	1.86	0.341
	7	11	80	20	98.2	22.8	125.9	0.900	8.765	7.415	0.846	42.1	46.8	1.85	0.335
	8	4	88	18	98.4	24.6	127.9	0.940	9.041	7.838	0.867	43.7	46.5	1.78	0.342
91	4	3	90	..	99.0	14.9	103.3	0.650	7.221	6.174	0.855	34.8	53.5	2.34	0.337
M	4	9	86	..	99.1	15.9	107.3	0.690	7.684	6.486	0.844	36.9	53.5	2.32	0.344
12/29/28	5	0	82	..	99.1	16.0	109.2	0.700	7.643	6.588	0.862	36.9	52.7	2.31	0.338
	5	4	80	..	98.8	16.3	110.1	0.710	7.792	6.499	0.834	37.3	52.6	2.29	0.339
	5	7	78	21	98.8	17.0	112.5	0.735	8.172	6.872	0.841	39.2	53.4	2.31	0.349
	5	10	78	19	98.4	17.9	114.4	0.760	7.633	6.908	0.905	37.3	49.0	2.08	0.326
	6	1	77	20	98.6	18.6	115.5	0.780	8.181	7.085	0.866	39.5	50.7	2.13	0.342
	6	7	78	23	98.6	19.4	118.5	0.810	8.922	7.512	0.842	42.8	52.9	2.21	0.362
	7	0	70	20	98.7	20.4	121.9	0.840	8.920	7.752	0.869	43.1	51.4	2.11	0.354
83	4	3	90	..	98.6	19.1	110.5	0.760	7.405	6.376	0.861	35.7	47.0	1.87	0.323
M	4	10	104	..	99.2	19.8	115.6	0.800	7.352	6.367	0.866	35.5	44.4	1.79	0.307
10/26/27	5	5	68	..	98.2	21.9	119.9	0.855	8.406	7.171	0.853	40.5	47.4	1.85	0.338
	5	10	74	..	98.3	21.9	123.9	0.875	7.879	6.753	0.857	38.0	43.4	1.73	0.307
	6	1	76	..	98.6	22.5	125.2	0.890	8.147	6.974	0.856	39.3	44.1	1.75	0.314
	6	5	82	..	98.0	23.1	125.5	0.905	8.520	7.012	0.823	40.7	45.0	1.76	0.324
	6	9	78	26	98.4	23.8	127.9	0.925	8.427	7.323	0.869	40.8	44.1	1.71	0.319
	7	1	81	24	98.4	24.8	129.1	0.950	8.610	7.155	0.831	41.2	43.4	1.66	0.319
	7	4	79	23	98.0	24.9	131.3	0.960	8.814	7.686	0.872	42.7	44.4	1.71	0.325
	7	11	78	20	98.0	27.1	134.9	1.020	8.405	6.800	0.809	40.0	39.2	1.48	0.297
	8	5	72	24	97.8	27.1	137.5	1.030	8.760	7.245	0.827	41.9	40.7	1.55	0.305
80	4	4	90	..	97.8	15.2	101.0	0.650	6.439	5.608	0.871	31.2	47.9	2.05	0.308
M	4	7	80	..	98.2	15.8	104.1	0.675	7.010	6.162	0.879	34.0	50.4	2.15	0.327
10/13/27	5	0	88	..	98.6	16.3	107.3	0.700	7.000	6.048	0.853	34.2	48.8	2.10	0.318
	5	3	68	..	98.4	16.1	109.2	0.705	6.993	6.133	0.877	33.9	48.1	2.11	0.310
	5	7	66	..	98.8	16.0	110.5	0.710	7.299	5.956	0.816	34.8	49.0	2.18	0.315
	5	10	68	..	98.2	15.9	112.1	0.715	7.301	6.249	0.856	35.2	49.2	2.21	0.314
	6	1	60	..	98.4	16.7	113.0	0.730	7.854	6.456	0.822	37.5	51.4	2.25	0.332
	6	4	64	..	97.7	17.2	114.9	0.750	7.730	6.493	0.840	37.1	49.5	2.16	0.323
	6	8	66	19	98.6	17.4	116.3	0.760	7.345	6.170	0.840	35.3	46.4	2.03	0.303
	6	10	64	19	98.8	17.2	117.9	0.760	7.600	6.225	0.819	36.3	47.7	2.11	0.308
	7	2	63	18	98.4	18.3	118.9	0.800	7.762	6.412	0.826	37.1	46.4	2.03	0.312
	7	5	62	18	98.2	18.6	119.9	0.805	8.108	6.835	0.843	38.9	48.4	2.09	0.325
	7	11	60	18	98.0	19.7	123.0	0.835	7.878	6.310	0.801	37.4	44.8	1.90	0.304
	8	3	72	22	98.4	20.5	124.4	0.855	8.118	6.933	0.854	39.1	45.7	1.91	0.314
84	4	7	84	..	....	19.4	109.8	0.760	8.457	7.653	0.905	41.3	54.3	2.13	0.376
M	5	1	76	..	99.0	20.3	113.7	0.800	7.511	6.662	0.887	36.5	45.6	1.80	0.321
2/5/28	5	4	77	..	98.8	21.0	117.5	0.830	8.100	6.893	0.851	39.0	47.0	1.86	0.332
	6	1	76	18	98.4	22.6	121.9	0.875	8.775	7.591	0.865	42.4	48.5	1.88	0.348

TABLE 10.—*Data of Individual Basal Metabolism Tests on Boys—Continued*

Subject, Sex, Date of Birth	Age Yr.	Age Mo.	Pulse Rate	Respiration Rate	Temperature, F.	Weight, Kg.	Height, Cm.	Body Surface, Sq. M.	Oxygen Consumed, L. per Hr.	Carbon Dioxide Produced, L. per Hr.	Respiratory Quotient	Cal./Hr.	Cal./Hr./Sq. M.	Cal./Hr./Kg.	Cal./Hr./Cm.
84 (cont.)	6	5	81	22	98.8	22.9	124.0	0.895	9.078	7.653	0.843	43.6	48.7	1.90	0.352
	6	9	84	28	97.9	23.7	126.8	0.920	9.787	7.957	0.813	46.6	50.7	1.97	0.368
	7	2	80	23	97.8	25.4	128.8	0.960	10.042	8.405	0.837	48.2	50.2	1.90	0.374
	7	6	73	21	98.6	25.4	131.7	0.980	9.051	7.621	0.842	43.5	44.3	1.71	0.330
	8	0	80	22	99.0	28.2	134.4	1.030	10.223	8.424	0.824	48.9	47.4	1.73	0.364
P.	4	8	88	..	99.0	22.2	119.4	0.860	9.206	7.954	0.864	44.5	51.7	2.00	0.372
M	5	1	82	..	98.2	23.4	123.8	0.900	9.534	8.094	0.849	45.9	51.0	1.96	0.370
4/20/28	5	4	72	..	98.4	23.6	125.7	0.910	9.717	7.909	0.814	46.3	50.9	1.96	0.369
	5	7	76	..	98.4	24.6	127.6	0.940	9.788	7.869	0.804	46.5	49.5	1.89	0.365
	5	10	72	..	98.6	24.7	128.3	0.945	9.981	8.644	0.866	48.2	51.0	1.95	0.376
	6	2	80	18	98.0	23.7	129.5	0.930	10.061	8.401	0.835	48.2	51.9	2.04	0.372
	6	4	84	18	99.0	26.0	131.7	0.980	9.788	8.271	0.845	47.0	48.0	1.81	0.357
	6	9	92	18	98.4	28.8	134.2	1.040	10.072	8.662	0.860	48.6	46.7	1.69	0.362
	7	0	80	21	98.6	29.3	136.4	1.060	10.061	8.965	0.891	48.9	46.2	1.67	0.359
1	4	10	78	..	99.0	19.8	114.9	0.790	8.117	6.713	0.827	38.8	49.1	1.96	0.338
M	5	1	90	..	99.4 R	20.9	115.3	0.815	8.658	7.178	0.829	41.4	50.8	1.98	0.359
10/3/27	5	5	76	..	98.4 R	22.0	116.2	0.840	9.089	7.689	0.846	43.7	52.0	1.99	0.376
	5	8	72	..	98.2	22.7	119.4	0.865	9.269	7.656	0.826	44.3	51.2	1.95	0.371
	6	0	70	..	98.4	22.7	121.4	0.875	8.511	7.073	0.831	40.8	46.6	1.80	0.336
	6	3	76	..	98.7	23.6	123.8	0.905	8.896	7.535	0.847	42.8	47.3	1.81	0.346
	6	8	72	22	98.6	23.6	125.0	0.910	8.714	6.954	0.798	41.4	45.5	1.75	0.331
	6	11	76	22	98.6	24.0	126.2	0.925	8.937	7.748	0.867	43.2	46.7	1.80	0.342
	7	6	69	22	98.2	26.9	130.4	0.985	9.190	7.784	0.847	44.2	44.9	1.64	0.339
J.	5	4	90	..	98.3	17.1	109.9	0.720	7.739	6.524	0.843	37.2	51.6	2.17	0.338
M	5	7	88	..	98.8	17.3	112.4	0.740	8.059	6.713	0.833	38.6	52.2	2.23	0.343
8/28/27	5	10	92	..	98.8	16.9	114.3	0.740	8.166	7.113	0.871	39.5	53.4	2.34	0.346
	6	1	80	..	98.6	18.4	115.6	0.775	8.627	7.092	0.822	41.2	53.2	2.24	0.357
	6	5	80	..	98.8	18.8	117.2	0.790	8.123	6.937	0.854	39.1	49.5	2.08	0.334
	6	11	88	25	98.6	19.3	118.4	0.810	8.713	7.293	0.837	41.8	51.6	2.17	0.353
	7	2	86	19	98.6	20.4	120.3	0.835	8.897	7.242	0.814	42.4	50.8	2.08	0.353
	7	7	76	20	98.2	21.2	122.9	0.860	8.247	7.397	0.897	40.2	46.7	1.89	0.327
	8	1	80	19	98.2	22.0	125.3	0.885	9.116	7.666	0.841	43.8	49.5	1.99	0.349
	8	5	69	22	98.1	22.9	126.6	0.905	8.716	7.365	0.845	41.9	46.3	1.83	0.331
K.	5	7	84	..	99.0	20.7	115.6	0.815	8.876	6.977	0.786	42.0	51.5	2.03	0.363
M	6	2	86	..	99.3	22.2	118.7	0.850	8.871	7.416	0.836	42.5	50.0	1.92	0.358
12/2/26	6	5	90	..	98.6	22.6	121.2	0.870	8.467	7.078	0.836	40.6	46.7	1.80	0.335
	6	9	76	..	98.4	22.7	122.7	0.880	9.564	7.852	0.821	45.7	51.9	2.01	0.372
	7	1	86	..	98.8	24.3	124.5	0.920	9.543	7.825	0.820	45.6	49.5	1.88	0.366
	7	5	78	..	98.6	24.6	126.5	0.930	9.368	7.625	0.814	44.7	48.0	1.82	0.353
	7	8	82	21	98.4	24.6	127.9	0.940	8.389	7.122	0.849	40.4	42.9	1.64	0.316
	8	2	81	19	98.4	26.9	129.4	0.980	9.389	7.990	0.851	45.2	46.1	1.68	0.349
	8	8	76	18	98.8	27.8	131.9	1.010	9.883	8.490	0.859	47.7	47.2	1.72	0.361
	9	2	68	18	98.4	29.3	134.5	1.050	9.855	7.943	0.806	46.9	44.6	1.60	0.349

								0.845	8.499	7.258	0.854	40.9	48.5	1.80	0.354
														1.80	0.367

M.	5	8	74	..	98.4	22.7	115.6	0.845	8.499	7.258	0.854	40.9	48.5	1.80	0.354
M	6	7	64	..	98.6	25.0	122.5	0.920	9.376	7.820	0.834	44.9	48.8	1.80	0.367
8/11/26	7	0	64	..	98.6	26.8	125.7	0.960	10.510	8.702	0.828	50.3	52.4	1.88	0.400
	7	7	64	20	98.2	27.3	128.9	0.985	9.577	8.045	0.840	46.0	46.7	1.68	0.357
	8	1	62	18	98.4	27.9	130.4	1.095	9.109	7.405	0.813	43.4	43.2	1.56	0.333
	8	7	55	29	98.0	29.3	133.6	1.040	10.141	8.833	0.871	49.1	47.2	1.67	0.367
	9	2	56	24	98.6	32.7	136.4	1.110	10.472	9.414	0.899	51.0	46.0	1.56	0.374
	9	6	72	23	98.7	32.9	138.3	1.130	10.596	8.636	0.815	50.5	44.7	1.54	0.365
B.	6	7	86	..	98.6	27.8	129.3	1.000	10.523	8.776	0.834	50.4	50.4	1.81	0.390
M	6	10	84	..	98.3	29.6	129.5	1.030	10.883	8.913	0.819	52.0	50.4	1.76	0.401
5/5/26	7	4	82	..	98.3	30.7	135.2	1.080	11.691	9.668	0.827	55.9	51.8	1.82	0.414
	7	7	82	..	98.6	32.8	135.9	1.115	11.836	10.262	0.867	57.2	51.3	1.74	0.421
	7	11	80	18	98.8	34.8	136.8	1.150	11.600	9.639	0.831	55.5	48.3	1.60	0.406
	8	2	90	22	98.6	36.7	138.0	1.185	11.496	10.197	0.887	55.9	47.1	1.52	0.405
	8	8	79	20	98.6	39.9	141.2	1.245	11.542	10.157	0.880	56.0	45.0	1.40	0.396
	8	11	77	22	98.6	40.8	143.8	1.275	10.846	9.957	0.918	53.1	41.7	1.30	0.369
	9	4	75	20	98.8	40.8	145.2	1.280	10.598	8.595	0.811	50.5	39.4	1.24	0.348
	9	8	63	24	97.6	44.2	147.8	1.335	12.007	10.038	0.836	57.6	43.1	1.30	0.390
56	7	1	90	..	99.4	25.1	127.0	0.940	10.110	7.997	0.791	47.9	51.0	1.91	0.377
M	7	5	80	..	99.2	24.2	129.5	0.940	10.550	8.419	0.798	50.1	53.3	2.07	0.387
1/18/25	7	8	84	..	98.6	25.6	132.1	0.975	10.181	8.817	0.866	49.2	50.5	1.92	0.372
	8	0	78	..	98.3	26.3	133.4	0.995	9.950	8.567	0.861	48.0	48.3	1.83	0.360
	8	3	78	..	98.7	26.8	134.6	1.010	10.186	8.699	0.854	49.1	48.6	1.83	0.365
	8	6	78	..	98.0	26.5	135.9	1.015	9.452	7.817	0.827	45.2	44.5	1.71	0.333
	9	1	82	..	98.4	28.6	137.9	1.055	11.144	8.949	0.803	53.0	50.2	1.85	0.384
	9	5	92	..	98.6	28.1	138.7	1.050	9.805	8.373	0.854	47.2	45.0	1.68	0.341
	10	2	78	20	98.0	30.4	143.0	1.115	10.618	9.110	0.858	51.2	45.9	1.68	0.358
	10	4	66	23	98.2	30.7	143.8	1.130	10.489	8.444	0.805	49.9	44.1	1.63	0.347
	10	10	75	22	98.6	31.8	146.0	1.160	11.489	9.398	0.818	54.8	47.3	1.72	0.376
	11	2	80	18	98.6	32.9	147.3	1.190	11.165	8.887	0.796	53.0	44.5	1.61	0.360
61	7	6	92	..	98.8	21.5	122.7	0.860	9.383	7.863	0.838	45.0	52.3	2.09	0.367
M	7	10	102	..	98.5	21.9	123.8	0.875	9.480	7.925	0.836	45.5	51.9	2.08	0.367
3/28/25	8	1	80	..	98.4	23.1	125.7	0.905	9.253	7.717	0.834	44.3	49.0	1.92	0.353
	8	4	76	..	98.6	23.0	127.6	0.915	9.936	8.346	0.840	47.7	52.1	2.07	0.374
	8	7	76	..	98.2	23.7	129.5	0.930	9.366	8.083	0.863	45.2	48.6	1.91	0.349
	8	11	70	..	98.6	24.7	130.6	0.955	9.990	8.412	0.842	48.0	50.2	1.94	0.367
	9	2	80	19	98.0	24.9	131.8	0.965	9.685	7.971	0.823	46.3	48.0	1.86	0.351
	9	5	80	20	98.4	25.3	132.9	0.975	9.089	8.362	0.920	44.5	45.7	1.76	0.335
	9	9	85	21	98.6	25.9	134.6	1.010	9.876	8.622	0.873	47.8	47.3	1.85	0.355
	10	6	72	22	98.4	28.6	138.6	1.060	10.229	9.339	0.913	50.0	47.2	1.75	0.361
	10	10	80	20	98.2	29.5	140.2	1.080	10.780	9.066	0.841	51.8	47.9	1.75	0.369
60	7	6	79	..	98.6	21.3	116.2	0.825	9.299	7.765	0.835	44.6	54.0	2.09	0.384
M	8	1	64	..	98.2	22.7	119.4	0.865	9.239	8.038	0.870	44.7	51.7	1.97	0.374
3/28/25	8	4	66	..	98.2	22.6	120.2	0.870	8.999	7.784	0.865	43.5	50.0	1.92	0.362
	8	7	72	..	98.4	23.1	123.2	0.890	9.753	8.417	0.863	47.1	52.9	2.04	0.382
	8	11	60	..	98.4	24.0	124.2	0.915	10.080	8.538	0.847	48.5	53.0	2.02	0.390
	9	2	62	17	98 0	23.9	125.3	0.920	9.355	7.961	0.851	45.0	48.9	1.88	0.359
	9	2	62	17	98.0	23.9	125.3	0.920	9.692	8.664	0.894	47.2	50.7	1.89	0.377
	9	9	65	..	98.4	25.3	126.8	0.945	10.194	8.807	0.864	49.2	52.1	1.95	0.388
	10	0	59	18	98 6	26.4	128.5	0.970	10.303	9.067	0.880	50.0	51.5	1.89	0.389
	10	6	64	..	98.6	27.9	130.4	1.005	10.003	8.673	0.867	48.4	48.1	1.73	0.371
	10	10	60	23	98.1	29.1	131.8	1.030	9.968	8.732	0.876	48.3	46.9	1.66	0.366

TABLE 10.—*Data of Individual Basal Metabolism Tests on Boys—Continued*

Subject, Sex, Date of Birth	Age Yr.	Age Mo.	Pulse Rate	Respiration Rate	Temperature, F.	Weight, Kg.	Height, Cm.	Body Surface, Sq. M.	Oxygen Consumed, L. per Hr.	Carbon Dioxide Produced, L. per Hr.	Respiratory Quotient	Cal./Hr.	Cal./Hr./Sp. M.	Cal./Hr./Kg.	Cal./Hr./Cm.
O, M	7	11	79	..	98.4	27.0	128.3	0.980	9.286	7.763	0.836	44.5	45.4	1.65	0.347
4/17/25	8	3	82	..	98.7	26.5	130.8	0.980	9.097	7.596	0.835	43.6	44.5	1.65	0.333
C.	7	11	70	..	98.0	29.3	130.8	1.030	10.640	8.554	0.804	50.6	49.1	1.73	0.387
M	8	2	66	..	98.1	31.3	133.4	1.080	9.671	8.375	0.866	46.7	43.3	1.49	0.350
4/10/25	8	6	70	..	97.4	32.2	135.2	1.105	10.724	8.933	0.833	51.4	46.5	1.60	0.380
	8	9	72	..	98.0	32.1	136.7	1.110	10.577	9.551	0.903	51.6	46.5	1.61	0.377
	9	1	72	..	97.7	34.7	136.8	1.145	11.698	9.639	0.824	55.9	48.8	1.61	0.409
	9	9	70	18	98.0	40.1	141.2	1.250	11.508	10.173	0.884	55.9	44.7	1.39	0.396
	9	11	64	17	98.0	41.3	141.9	1.270	11.750	10.427	0.887	57.1	45.0	1.38	0.403
	10	5	65	18	98.2	42.0	144.4	1.290	10.626	9.170	0.863	51.3	39.8	1.22	0.355
	10	9	62	20	98.0	42.6	145.8	1.305	12.454	10.150	0.815	59.4	45.5	1.39	0.407
48	8	0	82	..	98.2	26.3	134.6	1.005	9.372	7.779	0.830	44.9	44.6	1.71	0.333
M	8	4	78	..	97.7	28.0	136.5	1.040	8.514	6.803	0.799	40.4	38.9	1.44	0.296
5/31/24	8	10	74	..	98.2	29.0	139.7	1.080	9.196	7.513	0.817	43.9	40.6	1.51	0.314
	9	5	72	..	98.5	29.5	142.2	1.100	9.758	8.050	0.825	46.7	42.4	1.58	0.328
	9	7	72	..	98.3	30.8	143.0	1.125	10.032	8.938	0.891	48.8	43.4	1.58	0.341
	9	10	76	..	98.4	32.4	144.0	1.155	9.503	7.802	0.821	45.4	39.3	1.40	0.315
	10	2	72	17	97.8	31.8	145.0	1.150	10.650	8.701	0.817	50.8	44.2	1.60	0.350
	10	7	70	20	98 2	34.8	147.1	1.215	10.557	9.100	0.862	51.0	42.0	1.46	0.346
	10	9	75	18	98.2	34.0	148.2	1.205	10.317	8.747	0.848	49.6	41.2	1.46	0.335
	11	3	61	19	97.7	34.1	150.3	1.220	10.407	9.169	0.881	50.5	41.4	1.48	0.336
	11	5	76	18	97.8	35.8	151.4	1.250	11.092	8.973	0.809	52.8	42.2	1.48	0.349
	11	9	66	20	97.4	37.0	153.5	1.275	10.958	8.876	0.810	52.2	40.9	1.41	0.340
31, M	8	3	74	..	98.4	26.8	128.3	0.975	9.082	7.792	0.858	43.8	44.9	1.63	0.341
1/18/24	8	8	96	..	98.6	27.2	132.1	1.000	9.224	7.206	0.781	43.6	43.6	1.60	0.330
R.	8	3	84	..	98.6	27.7	127.0	0.980	9.501	7.696	0.810	45.2	46.2	1.63	0.356
M	8	8	96	..	98.0	28.4	130.4	1.010	9.322	7.616	0.817	44.5	44.0	1.57	0.341
7/20/25	9	2	84	21	98.2	29.3	131.1	1.030	9.320	7.950	0.853	44.9	43.6	1.53	0.342
	9	5	88	18	97.9	30.7	134.2	1.070	9.134	7.746	0.848	43.9	41.1	1.43	0.327
	9	9	92	24	98.0	32.2	135.5	1.100	9.342	7.922	0.848	44.9	40.8	1.40	0.332
	10	2	82	21	97.9	32.4	136.5	1.110	9.958	8.126	0.816	47.5	42.8	1.47	0.348
	10	6	78	18	97.8	34.5	138.2	1.150	10.075	8.352	0.829	48.2	41.9	1.40	0.349
42	8	4	80	..	98.6	31.2	133.4	1.070	10.294	8.287	0.805	49.0	45.8	1.57	0.367
M	8	10	64	..	98.5	34.5	135.2	1.130	10.306	8.049	0.781	48.7	43.1	1.41	0.360
5/17/24	9	1	64	..	98.2	33.4	137.8	1.130	9.404	8.557	0.910	46.0	40.7	1.38	0.333
	9	8	72	..	98.4	35.6	140.3	1.185	10.914	9.493	0.870	52.8	44.5	1.48	0.376
	10	2	64	16	98.2	34.3	142.0	1.175	9.567	8.314	0.869	46.3	39.4	1.35	0.326
	10	10	59	15	98.2	41.6	145.7	1.290	11.649	9.937	0.853	56.1	43.5	1.35	0.385
	11	2	74	19	98.1	42.3	146.7	1.310	11.689	9.877	0.845	56.2	42.9	1.33	0.383
20	8	8	76	..	98.2	24.3	133.9	0.970	9.147	8.067	0.882	44.4	45.8	1.83	0.331
M	8	11	74	..	98.6	25.4	135.4	0.995	9.629	8.069	0.838	46.2	46.4	1.82	0.341
10/16/23	9	2	72	..	98.2	25.2	137.8	1.005	10.061	8.713	0.866	48.6	48.4	1.93	0.353

20 (cont.)	9	5	66	..	98.0	27.2	139.7	1.045	9.041	7.540	0.834	43.3	41.5	1.59	0.310
	9	8	76	..	98.6	27.4	140.3	1.055	10.126	8.506	0.840	48.6	46.1	1.77	0.346
	10	0	66	..	98.4	28.8	141.6	1.085	9.808	8.405	0.857	47.3	43.6	1.64	0.334
	10	2	64	..	98.2	29.6	144.2	1.115	10.123	8.655	0.855	48.8	43.7	1.65	0.338
	10	6	68	20	98.2	29.9	144.4	1.120	10.411	8.620	0.828	49.8	44.5	1.67	0.345
	10	9	72	23	98.6	31.3	145.0	1.140	9.955	8.312	0.835	47.7	41.9	1.52	0.329
	11	3	75	26	98 2	33.0	148.8	1.195	11.225	9.159	0.816	53.5	44.8	1.62	0.360
	12	1	62	24	97.8	35.9	153.0	1.260	12.011	9.596	0.799	57.0	45.3	1.59	0.373
	12	4	60	19	97 6	36.3	154.8	1.275	11.407	10.015	0.878	55.3	43.4	1.52	0.357
17	9	0	68	..	98.0	24.1	126.3	0.925	9.516	8.146	0.856	45.9	49.6	1.90	0.363
M	9	3	68	..	98.0	25.2	127.6	0.950	9.837	8.155	0.829	47.1	49.6	1.87	0.369
7/5/23	9	10	74	..	98.7	26.2	130.8	0.960	9.300	8.035	0.864	44.9	45.8	1.71	0.343
	11	9	70	14	97.9	29.5	137.6	1.070	9.396	7.892	0.840	45.1	42.1	1.53	0.328
13	9	3	70	..	98.8	26.8	132.1	1.000	10.297	8.196	0.796	48.9	48.9	1.82	0.370
M	10	0	78	..	98.6	29.3	136.5	1.060	11.509	9.150	0.795	54.6	51.5	1.86	0.400
10/16/22	10	6	64	..	97.8	30.4	139.0	1.095	11.024	9.382	0.851	53.1	48.5	1.75	0.382
	10	9	66	..	98.0	29.1	139.7	1.060	10.807	8.948	0.828	51.7	47.9	1.78	0.370
14	9	6	64	..	98.3	30.7	139.1	1.100	10.038	8.422	0.839	48.2	43.8	1.57	0.346
M	9	10	66	..	98.4	33.5	141.0	1.150	10.996	9.380	0.853	53.0	46.1	1.58	0.376
12/5/22	10	2	66	..	98.4	34.9	143.5	1.195	11.755	10.015	0.852	56.6	47.4	1.62	0.394
	12	1	55	15	97.8	40.9	153.9	1.330	11.879	9.860	0.830	56.9	42.8	1.39	0.369
	12	3	64	20	98.2	43.3	155.2	1.370	11.951	10.732	0.898	58.2	42.5	1.34	0.375
	12	8	64	16	97.8	47.7	159.5	1.470	12.171	10.029	0.824	58.2	39.6	1.22	0.365
	12	11	64	18	97.4	51.9	162.5	1.540	14.574	11.586	0.795	69.1	44.9	1.33	0.425
15	9	6	78	..	98.9	24.5	134.6	0.970	9.386	7.856	0.837	45.0	46.4	1.84	0.334
M	10	0	84	..	98.6	26.9	137.7	1.030	9.121	7.434	0.815	43.5	42.2	1.62	0.316
12/29/22	10	3	80	..	98.7	27.7	138.4	1.050	9.400	7.642	0.813	44.8	42.7	1.62	0.324
	10	6	70	..	98.7	27.2	139.0	1.040	9.415	7.956	0.845	45.3	43.5	1.66	0.326
	10	10	72	..	98.2	28.4	142.2	1.080	10.134	8.442	0.833	48.6	45.0	1.71	0.341
	11	2	70	..	98.2	28.4	143.0	1.085	9.060	7.529	0.831	43.4	40.0	1.53	0.303
	11	6	78	23	99.0	29.6	143.8	1.110	9.739	8.015	0.823	46.5	41.9	1.57	0.324
	11	11	76	20	98.4	29.9	145.6	1.125	9.155	7.763	0.848	44.0	39.1	1.47	0.302
	12	3	76	17	97.8	31.8	146.8	1.160	9.024	7.427	0.823	43.1	37.2	1.36	0.294
	12	6	76	19	98.6	32.3	148.3	1.180	9.834	8.044	0.818	46.9	39.8	1.45	0.316
	12	11	78	16	98.2	34.0	151.6	1.225	10.856	9.141	0.842	52.1	42.6	1.53	0.344
12	9	9	68	..	98.6	28.8	132.7	1.035	8.984	7.726	0.860	43.4	41.9	1.51	0.327
M	10	1	70	..	98.4	28.9	135.2	1.050	9.522	7.865	0.826	45.5	43.4	1.58	0.337
8/28/22	10	4	70	..	98.4	29.9	135.2	1.070	10.397	8.546	0.822	49.7	46.4	1.66	0.367
	10	7	64	..	98.4	29.9	137.2	1.080	8.818	7.883	0.894	42.9	39.7	1.44	0.313
	10	11	60	..	98.0	28.9	137.7	1.060	9.112	7.754	0.851	43.9	41.4	1.52	0.319
	11	2	62	..	98.2	31.1	139.7	1.110	8.965	7.316	0.816	42.8	38.5	1.37	0.306
	12	4	67	21	98.0	33.8	144.3	1.185	9.897	8.284	0.837	47.5	40.1	1.40	0.329
	12	6	64	18	98.0	34.9	144.4	1.195	10.304	8.769	0.851	49.6	41.5	1.42	0.343
	12	11	64	20	98.0	35.6	145.5	1.210	9.264	8.078	0.872	44.8	37.1	1.26	0.308
10	9	11	68	..	98.0	29.1	134.6	1.050	9.758	8.109	0.831	46.7	44.5	1.61	0.347
M	10	3	70	..	98 4	29.9	135.2	1.060	9.263	8.078	0.872	44.8	42.3	1.50	0.332
8/11/22	10	9	70	..	97.8	31.9	139.1	1.120	9.435	8.123	0.861	45.5	40.7	1.43	0.327
	12	8	76	18	97.5	38.7	148.8	1.270	11.923	9.789	0.821	56.9	44.8	1.47	0.383
7, M	10	6	64	..	98.0	29.4	136.5	1.065	10.179	8.784	0.863	49.2	46.2	1.67	0.360
4/27/22															

TABLE 11.—*Data of Individual Basal Metabolism Tests on Girls*

Subject, Sex, Date of Birth	Age		Pulse Rate	Respiration Rate	Temperature, F.	Weight, Kg.	Height, Cm.	Body Surface, Sq. M.	Oxygen Consumed, L. per Hr.	Carbon Dioxide Produced, L. per Hr.	Respiratory Quotient	Cal./Hr.	Cal./Hr./Sq. M.	Cal./Hr./Kg.	Cal./Hr./Cm.
	Yr.	Mo.													
46	2	0	92	..	98.0 R	12.9	91.6	0.560	6.169	5.052	0.819	29.4	52.6	2.28	0.321
F	2	3	84	..	98.8 R	13.3	93.0	0.580	6.321	5.278	0.835	30.3	52.2	2.28	0.326
9/23/31	2	10	..	26	98.6 R	14.7	97.8	0.630	6.557	5.501	0.839	31.5	49.9	2.14	0.322
	3	1	88	23	99.0 R	15.5	100.1	0.655	6.661	6.015	0.903	32.5	49.6	2.10	0.325
	3	4	88	25	98.6 R	15.9	102.4	0.670	6.637	5.568	0.839	31.8	47.5	2.00	0.311
	3	10	78	19	99.0 R	16.8	104.6	0.695	6.826	5.741	0.841	32.8	47.2	1.95	0.313
	4	3	92	23	99.4	17.9	108.3	0.730	7.878	6.877	0.873	38.1	52.2	2.13	0.352
94	2	0	100	25	98.9 R	13.8	87.7	0.560	6.264	5.287	0.844	30.1	53.7	2.18	0.343
F	2	3	91	23	98.4 R	14.6	90.7	0.590	6.470	5.500	0.850	31.1	52.8	2.13	0.343
7/11/32	2	7	100	25	98.7 R	15.5	92.7	0.620	6.589	5.601	0.850	31.7	51.1	2.05	0.342
	3	1	92	20	98.8 R	16.2	97.5	0.650	6.834	5.782	0.846	32.9	50.5	2.03	0.337
	3	4	90	24	99.0 R	17.2	99.3	0.675	6.924	5.837	0.843	33.3	49.3	1.93	0.335
50, F	2	0	100	..	98.4 R	12.2	89.1	0.540	5.617	4.679	0.833	26.9	49.8	2.21	0.302
9/13/31	3	7	102	26	98.8 R	15.2	103.0	0.660	7.131	5.769	0.809	34.0	51.4	2.23	0.330
71	2	0	98	..	98.2 R	10.3	86.7	0.490	5.304	4.440	0.837	25.4	51.9	2.47	0.293
F	2	6	115	24	98.2 R	11.6	93.0	0.540	5.682	4.705	0.828	27.2	50.3	2.34	0.292
3/28/32	2	10	100	24	98.6 R	12.0	95.8	0.565	6.191	5.083	0.821	29.6	52.3	2.46	0.309
	3	4	92	19	98.8 R	12.0	99.5	0.575	6.268	5.415	0.864	30.3	52.7	2.52	0.304
41, F	2	1	102	30	.....	12.1	84.9	0.520	5.686	4.412	0.776	26.8	51.6	2.22	0.316
9/15/33	2	5	82	23	98.9 R	13.0	87.3	0.550	5.938	5.315	0.895	28.9	52.6	2.22	0.331
53	2	1	96	34	98.6 R	11.9	89.8	9.535	6.069	5.007	0.825	29.0	54.2	2.44	0.323
F	2	5	86	24	98.6 R	12.5	92.9	0.560	5.934	4.854	0.818	28.3	50.6	2.27	0.305
9/26/32	2	11	85	25	98.6 R	14.1	97.3	0.610	6.660	5.534	0.831	31.9	52.3	2.26	0.328
	3	3	84	25	98.6 R	14.9	100.0	0.640	6.802	5.700	0.838	32.6	51.0	2.19	0.326
79	2	2	98	..	98.6 R	12.7	90.9	0.555	5.877	4.796	0.816	28.0	50.5	2.21	0.308
F	2	2	95	26	98.4 R	12.9	92.5	0.570	6.237	5.551	0.890	30 3	53 2	2.35	0.328
5/30/32	2	5	88	..	98.4 R	13.6	94.5	0.590	6.360	5.699	0.896	31.0	52.5	2.28	0.328
	3	7	78	22	98.2 R	16.2	103.1	0.675	7.403	6.485	0.876	35.9	53.1	2.21	0.348
54	2	2	98	..	99.4 R	12.8	92.2	0.565	6.072	4.917	0.810	28.9	51.2	2.26	0.314
F	2	8	84	24	99.0 R	13.5	96.9	0.595	5.914	5.281	0.893	28.8	48.4	2.13	0.297
12/16/31	2	11	87	23	99.0 R	15.1	98.8	0.640	6.359	5.233	0.823	30.4	47.5	2.01	0.308
	3	2	90	24	99.2 R	15.3	100.0	0.650	6.384	5.573	0.873	30.9	47.5	2.02	0.309
	3	9	78	24	99 2 R	16.8	106.4	0.700	6.638	5.881	0.886	32.2	46.1	1.92	0.303
43	2	2	104	..	98.8 R	12.9	93.8	0.570	6.269	5.022	0.801	29.8	52.3	2.31	0.318
F	2	6	100	..	98.6 R	13.6	96.5	0.600	6.510	5.625	0.864	31.4	52.4	2.31	0.326
9/9/31	2	9	92	22	99.2 R	14.6	99.5	0.630	6.439	5.396	0.838	30.9	49.0	2.12	0.310
	3	7	92	..	99.8	17.0	104.9	0.695	7.056	5.814	0.824	33.7	48.5	1.98	0.322
87	2	3	80	..	98.6 R	10.2	84.0	0.480	5.411	4.681	0.865	26.1	54.5	2.56	0.311
F	2	7	..	..	.....	10.8	87.0	0.500	5.250	4.342	0.827	25.1	50.2	2.33	0.289
6/19/32	2	7	102	..	98.9 R	10.8	87.0	0.500	5.165	4.272	0.827	24.7	49.4	2.29	0.284
	2	11	99	..	98.6 R	11.6	90.1	0.530	5.575	4.778	0.857	26.9	50.7	2.32	0.298
	3	4	98	22	98.2 R	12.6	93.4	0.565	6.026	5.273	0.875	29.2	51.7	2.32	0.313
	3	7	92	24	98.6 R	12.8	94.8	0.570	5.894	5.263	0.893	28.7	50.3	2.24	0.303

TABLE 11.—*Data of Individual Basal Metabolism Tests on Girls—Continued*

Subject, Sex, Date of Birth	Age		Pulse Rate	Respiration Rate	Temperature, F.	Weight, Kg.	Height, Cm.	Body Surface, Sq. M.	Oxygen Consumed, L. per Hr.	Carbon Dioxide Produced, L. per Hr.	Respiratory Quotient	Cal./Hr.	Cal./Hr./Sq. M.	Cal./Hr./Kg.	Cal./Hr./Cm.
	Yr.	Mo.													
95	3	2	88	..	99.1 R	15.9	97.5	0.650	6.776	5.658	0.835	32.5	50.0	2.04	0.333
F	3	8	92	..	99.4 R	16.3	100.3	0.665	7.047	5.878	0.834	33.8	50.8	2.07	0.337
6/10/29	3	11	106	..	99.1 R	17.1	102.2	0.690	7.567	6.136	0.811	36.0	52.2	2.11	0.353
	4	3	94	..	99.2 R	18.2	104.7	0.715	7.652	6.267	0.819	36.5	51.1	2.01	0.349
	4	7	98	..	99.2 R	18.9	107.9	0.740	8.086	6.566	0.812	38.5	52.1	2.04	0.357
	4	10	91	..	98.4	19.6	109.1	0.760	8.198	6.575	0.802	39.0	51.3	1.99	0.357
	5	2	88	..	98.6	19.7	111.3	0.775	7.252	6.113	0.843	34.8	44.9	1.77	0.313
	5	6	83	21	98.0	20.5	113.6	0.805	7.406	6.228	0.841	35.6	44.2	1.73	0.313
	5	9	90	16	98.6	20.6	115.1	0.815	8.236	6.836	0.830	39.4	48.4	1.91	0.343
	6	3	79	21	98.2	21.9	117.3	0.845	8.079	6.673	0.826	38.6	45.7	1.76	0.329
	6	7	78	22	98.8	22.1	118.9	0.850	8.063	6.934	0.860	38.9	45.8	1.76	0.327
22	3	3	98	..	99.0 R	14.3	99.0	0.625	6.801	5.699	0.838	32.6	52.2	2.28	0.330
F	3	8	90	20	98.7 R	14.6	101.1	0.640	6.507	5.206	0.800	30.9	48.3	2.12	0.306
10/10/30	4	0	88	26	98.6 R	16.1	104.2	0.680	6.595	5.612	0.851	31.7	46.7	1.97	0.305
3	3	8	106	..	99.0 R	12.4	95.0	0.570	6.057	5.100	0.842	29.1	51.0	2.35	0.306
F	3	11	102	..	99.0 R	12.4	97.2	0.590	6.860	5.646	0.823	32.8	55.6	2.65	0.337
4/29/30	4	3	94	20	98.8 R	12.6	98.8	0.595	6.501	5.481	0.843	31.2	52.5	2.48	0.316
	4	6	92	21	98.1 R	13.4	100.9	0.610	6.621	5.879	0.888	32.2	52.7	2.40	0.319
	4	9	96	20	98.9 R	13.9	102.3	0.635	7.143	5.843	0.818	34.1	53.7	2.45	0.333
	5	3	89	27	99.0 R	14.2	104.8	0.645	7.115	5.884	0.827	34.0	52.8	2.40	0.325
90	3	9	92	..	98.8	17.8	109.8	0.735	7.935	6.570	0.828	38.0	51.6	2.13	0.346
F	4	3	72	..	98.6	18.9	112.4	0.770	8.051	6.771	0.841	38.7	50.2	2.05	0.344
11/30/28	4	6	72	..	98.2	19.7	115.6	0.800	7.927	6.754	0.852	38.2	47.7	1.94	0.330
	4	11	76	..	98.6	20.8	118.7	0.830	8.101	6.554	0.809	38.6	46.5	1.85	0.325
	5	6	72	19	98.7	22.6	122.8	0.880	9.154	7.424	0.811	43.6	49.5	1.93	0.355
	5	10	76	20	98.4	23.9	125.3	0.915	8.165	6.850	0.839	39.2	42.8	1.64	0.313
	6	3	79	18	98.4	24.8	127.9	0.940	8.942	7.887	0.882	43.4	46.2	1.75	0.339
	6	10	81	19	98.7	25.5	131.5	0.975	9.512	7.610	0.800	45.2	46.3	1.77	0.344
	7	0	80	20	98.6	26.8	131.9	1.000	9.568	7.903	0.826	45.8	45.8	1.71	0.347
	7	3	72	22	98.8	27.4	133.2	1.015	9.195	7.614	0.828	44.0	43.3	1.61	0.330
89	4	1	78	..	98.4	14.7	103.5	0.650	6.488	5.696	0.878	31.4	48.4	2.14	0.304
F	4	6	82	..	98.3	15.9	106.7	0.690	7.374	6.105	0.828	35.3	51.1	2.22	0.331
9/21/28	4	9	82	..	98.6	15.4	106.6	0.690	7.347	6.222	0.847	35.3	51.1	2.29	0.325
	5	1	80	..	98.4	16.8	109.8	0.720	7.889	6.406	0.812	37.6	52.2	2.24	0.342
	5	4	74	..	98.4	17.6	111.8	0.740	7.342	6.196	0.844	35.3	47.7	2.00	0.316
	5	8	76	..	98.6	17.7	113.2	0.750	7.774	6.825	0.878	37.7	50.2	2.13	0.333
	5	11	76	20	98.2	18.4	115.3	0.775	7.519	6.421	0.854	36.2	46.7	1.97	0.314
	6	4	76	20	98.3	20.2	117.9	0.820	7.496	6.551	0.874	36.3	44.3	1.80	0.308
	6	10	72	25	98.2	20.4	120.3	0.840	8.189	6.977	0.852	39.4	46.9	1.93	0.328
	7	3	70	21	98.6	22.1	123.2	0.875	8.321	7.215	0.867	40.2	46.0	1.82	0.326
86	4	1	92	..	99.2 R	18.3	101.6	0.700	7.294	6.317	0.866	35.2	50.4	1.93	0.347
F	4	4	104	..	98.6 R	18.7	104.8	0.725	7.111	6.421	0.903	34.7	47.9	1.86	0.331
3/24/28	4	7	80	..	98.6	19.0	106.0	0.735	7.485	6.258	0.836	35.9	48.8	1.89	0.339

	4	10	88	..	97.9	20 5	109.2	0.780	8.380	6.922	0.826	40.1	51.4	1.95	0.367
	5	1	78	..	98.4	20.9	110.0	0.785	8.115	6.784	0.836	38.9	49.6	1.86	0.354
	5	5	84	..	98.2	20.2	111.8	0.785	7.676	6.433	0.838	36.8	46.9	1.82	0.329
	5	9	88	..	98.3	21.3	113.6	0.820	8.465	7.119	0.841	40.6	49.6	1.91	0.358
	6	3	87	..	98.4	22.0	115.1	0.835	8.694	7.242	0.833	41.6	49.9	1.89	0.362
	6	9	83	21	98.4	24.2	117.1	0.880	8.195	6.695	0.817	39.1	44.4	1.62	0.334
	7	1	90	22	98.1	24.9	119.6	0.905	8.367	7.513	0.898	40.8	45.0	1.64	0.341
85	4	2	84	..	98.7	19.5	109.8	0.760	6.898	6.070	0.880	33.5	44.0	1.72	0.305
F	4	6	88	..	98.7	20.7	113.0	0.805	6.919	6.186	0.894	33.7	41.8	1.63	0.298
2/2/28	5	1	88	..	98.6	22.0	118.7	0.850	7.400	6.778	0.916	36.2	42.6	1.65	0.305
	5	4	84	..	99.0	23.5	121.9	0.895	8.205	7.327	0.893	39.9	44.6	1.70	0.328
	6	3	96	..	99.2	24.0	126.0	0.925	8.571	7.226	0.843	41.2	44.5	1.72	0.327
	6	6	88	..	98.4	27.1	129.1	0.990	8.945	7.746	0.866	43.2	43.7	1.59	0.335
	6	10	93	..	99.0	28.4	131.1	1.020	8.909	7.804	0.876	43.2	42.3	1.52	0.329
	7	1	93	16	98.7	30.5	133.6	1.065	9.962	8.275	0.829	47.8	44.9	1.57	0.358
	7	6	84	18	98.6	32.7	135.9	1.110	9.439	8.155	0.864	45.6	41.1	1.39	0.336
78	4	5	96	..	98.0	17.1	106.3	0.705	7.664	6.047	0.789	36.3	51.5	2.12	0.341
F	4	11	84	..	98.6	17.4	111.3	0.735	7.306	6.437	0.881	35.4	48.2	2.04	0.318
9/13/27	5	2	70	..	98.2	18.3	111.8	0.755	8.033	6.780	0.844	38.6	51.1	2.11	0.345
	5	5	66	..	98.3	18.5	112.4	0.760	7.997	6.742	0.843	38.4	50.5	2.08	0.342
	5	8	72	..	98.3	19.3	116.1	0.795	7.235	6.085	0.841	34.7	43.7	1.80	0.299
	6	2	74	..	98.4	19.7	119.4	0.820	7.814	6.688	0.856	37.7	45.9	1.91	0.315
	6	5	86	..	98.4	21.0	120.7	0.845	9.132	7.635	0.836	43.8	51.8	2.09	0.363
	6	9	82	24	98.6	22.1	122.7	0.8,0	8.493	7.040	0.829	40.6	46.7	1.84	0.331
	7	1	82	21	98.4	22.8	124.1	0.895	8.020	6.793	0.847	38.6	43.1	1.69	0.311
	7	6	76	20	98.6	23.8	126.6	0.920	8.754	7.319	0.836	42 0	45.6	1.76	0.332
	8	0	85	..	98.2	22.5	128.9	0.910	9.136	7.601	0.832	43.8	48.1	1.94	0.339
	8	3	76	24	98.6	24.9	130.6	0.965	9.284	7.799	0.840	44.6	46.2	1.79	0.341
73	4	8	90	..	98.9	15.1	104.1	0.665	6.605	5.827	0.882	32.1	48.2	2.12	0.308
F	5	0	90	..	98.9	15.8	104.1	0.675	7.102	6.235	0.878	34.4	51.0	2.18	0.331
5/12/27	5	4	84	..	98.8	15.8	104.7	0.680	6.652	5.488	0.825	31.8	46.8	2.01	0.304
	5	9	88	..	98.6	16.7	110.5	0.720	7.211	6.209	0.861	34.8	48.3	2.08	0.315
	6	0	90	..	98.8	16.2	111.8	0.715	7.446	6.038	0.811	35.5	49.6	2.19	0.317
	6	3	86	..	98.8	16.7	113.0	0.735	7.419	6.373	0.859	35.8	48.7	2.14	0.317
	6	7	84	..	98.6	17.2	114.8	0.750	7.436	6.454	0.868	35.9	47.9	2.09	0.313
	6	9	96	..	98.6	17.9	115.7	0.770	7.531	6.402	0.850	36.2	47.1	2.02	0.313
	7	0	82	..	98.4	18.1	116.6	0.775	7.469	6.498	0.870	36.1	46.6	2.00	0.310
	7	3	96	24	98.4	19.2	117.9	0.805	7.556	6.498	0.860	36.5	45.3	1.90	0.309
	7	6	88	..	98.6	20.5	119.0	0.830	7.974	6.276	0.787	37.8	45.5	1.84	0.317
	8	3	88	24	98.6	21.8	122.4	0.865	8.144	7.053	0.866	39.4	45.5	1 81	0.322
72	4	11	90	..	98.0	16.4	108.0	0.700	7.329	6.119	0.835	35.1	50.2	2.14	0.325
F	5	2	84	..	98.4	16.3	108.6	0.700	7.064	6.096	0.863	34.1	48.7	2.09	0.314
6/1/27	5	8	76	..	98.6	18.2	111.8	0.750	7.517	6.314	0.840	36.1	48.1	1.98	0.323
	5	11	76	..	98.6	18.2	113.0	0.760	7.598	6.443	0.848	36.5	48.1	2.01	0.323
	6	2	72	..	98.6	18.4	114.9	0.770	7.755	6.522	0.841	37.2	48.4	2.02	0.324
	6	5	80	..	98.8	20.0	116.8	0.810	7.819	6.404	0.819	37.3	46.1	1.87	0.320
	6	8	74	..	98.4	20.0	118.9	0.820	8.164	6.801	0.833	39.1	47.7	1.96	0.329
	7	0	64	..	98.6	21.0	119.0	0 835	8.083	6.558	0.811	38.5	46.1	1.83	0.324
	7	6	78	28	98.5	21.8	121.7	0.860	8.439	7.418	0.879	40.9	47.6	1.88	0.336
	8	4	68	20	98.5	26.1	128.2	0.970	9.248	8.083	0.874	44.8	46.2	1.72	0.349
	8	8	64	20	98.6	26.5	129.7	0.980	9.394	7.684	0.818	44.8	45.7	1.69	0.346

TABLE 11.—*Data of Individual Basal Metabolism Tests on Girls—Continued*

Subject, Sex, Date of Birth	Age Yr.	Age Mo.	Pulse Rate	Respiration Rate	Temperature, F.	Weight, Kg.	Height, Cm.	Body Surface, Sq. M.	Oxygen Consumed, L. per Hr.	Carbon Dioxide Produced, L. per Hr.	Respiratory Quotient	Cal./Hr.	Cal./Hr./Sq. M.	Cal./Hr./Kg.	Cal./Hr./Cm.
69	5	4	80	..	99.0	21.2	116.2	0.830	7.862	6.926	0.881	38.1	45.9	1 80	0.328
F	5	7	80	..	99.0	21.8	118.1	0.845	9.001	7.408	0.823	43.0	50 9	1.97	0.364
2/24/27	5	10	72	..	98.4	22.0	119.4	0.855	9.024	7.590	0.841	43.3	50.7	1.97	0.363
	6	1	76	..	99.0	22.6	120.7	0.875	8.861	7.097	0.801	42.1	48.1	1.86	0.349
	6	4	80	..	98.9	23.7	123.2	0.905	9.552	8.186	0.857	46.1	50.9	1.94	0.374
	6	9	68	..	98.6	25.9	125.7	0.955	8.659	6.962	0.804	41.2	43.1	1.59	0.328
	7	1	72	..	98.3	25.4	127.0	0.955	9.138	7.758	0.849	44.0	46.0	1.73	0.346
	7	8	80	19	98.6	27.2	129.1	0.990	9.187	7.432	0.809	43.7	44.2	1.61	0.339
	8	0	76	16	98.3	28.9	131.3	1.030	10.059	8.088	0.804	47.8	46.4	1.66	0.364
	8	9	76	16	98.5	30.8	135.8	1.085	9.113	7.245	0.795	43.2	39.8	1.40	0.318
70	5	10	80	..	98.5	21.5	123.2	0.865	8.377	7.146	0.853	40.3	46.6	1.88	0.327
F	6	2	80	..	98.6	22.1	123.8	0.880	8.158	6.943	0.851	39.3	44.6	1.78	0.317
3/26/27	6	5	84	..	98.6	21.1	127.0	0.875	8.254	6.619	0.802	39.2	44.8	1.86	0.309
	8	8	84	..	99.0	22.7	127.6	0.910	8.891	7.486	0.842	42.7	46.9	1.88	0.335
	6	11	82	..	99.0	23 8	128.7	0.935	8.986	7.476	0 832	43.0	46.0	1.81	0.334
	7	2	78	..	98.2	23.7	129.8	0.940	8.092	6.514	0.805	38.5	40.9	1 62	0.296
	7	5	84	17	98.6	24.8	131.1	0.970	8.246	7.471	0.906	40.3	41.5	1.62	0.307
	7	10	85	21	98.4	26.5	133.9	1.005	8.838	7.424	0.840	42.4	42.2	1.60	0.317
	8	1	90	20	98.6	27.2	135.1	1.025	9.001	7.642	0.849	43.3	42.2	1.59	0.321
	8	9	72	17	98.6	30.1	140.0	1.090	9.210	8.206	0.891	44.8	41.1	1.49	0.320
64	6	1	92	..	98.3	26.1	124.5	0.945	9.502	8.191	0.862	45.9	48.5	1.76	0.368
F	6	2	76	..	97.7	27.5	125.7	0.970	9.364	7.707	0.823	44.7	46.1	1.63	0.356
2/6/26	6	4	69	..	97.2	27.9	126.3	0.980	9.703	8.335	0.859	46.8	47.8	1.68	0.371
	6	8	74	..	98.5	29.8	129.5	1.030	9.685	8.416	0.869	46.8	45.5	1.57	0.362
	7	8	100	..	98.4	29.8	137.2	1.070	10.385	8.692	0.837	49.8	46.5	1.67	0.363
	7	11	78	..	98.4	33.7	139.0	1.145	10.241	8.643	0.844	49.2	43.0	1.46	0.354
	8	3	66	..	98.6	34.0	139.9	1.155	9.700	8.197	0.845	46.6	40.4	1.37	0.333
	8	6	64	22	98.5	35.6	142.0	1.195	9.395	7.760	0.826	44.9	37.6	1.26	0.316
	8	10	70	15	98.4	38.0	144.4	1.240	9.842	8.759	0.890	47.9	38.6	1.26	0.331
	9	5	64	17	98.6	40.7	147.0	1.295	10.854	9.106	0.839	52.1	40.2	1.28	0.354
58	7	3	90	..	98.8	22.5	120.6	0.865	8.203	7.145	0.871	39.7	45.9	1.76	0.329
F	8	8	90	..	98.6	25.2	128.3	0.960	9.191	7.564	0.823	43.9	45.7	1.74	0.342
4/21/25	8	11	80	..	98.4	26.2	128.8	0.970	9.498	8.567	0.902	46.3	47.8	1.77	0.360
	9	2	83	15	98.6	25.4	130.3	0.970	9.024	7.626	0.845	43.4	44.7	1.71	0.333
	9	6	78	17	98.8	26.8	131.7	0.995	8.944	7.217	0.807	42.6	42.8	1.59	0.323
E.	7	5	82	..	98.8	23.5	124.5	0.905	8.948	7.660	0.856	43.1	47.7	1.84	0.346
F	7	11	86	..	99.2	24.5	127.6	0.940	9.488	7.961	0.839	45.5	48.4	1.86	0.357
7/19/25	8	3	84	..	98.4	26.5	128.3	0.980	9.486	7.921	0.835	45.5	46.4	1.72	0.354
	8	6	76	..	98.3	27.7	130.8	1.005	9.367	8.028	0.857	45.2	44.9	1.63	0.345
	8	9	70	..	98.6	28.1	131.4	1.010	9.291	7.888	0.849	44.7	44.3	1.59	0.340
	9	0	78	22	98.6	30.4	132.6	1.060	9.836	7.840	0.797	46.7	44.0	1.54	0.352
	9	3	76	24	98.4	32.1	135.4	1.100	9.425	7.785	0.826	45.1	41.0	1.40	0.333
	9	7	78	20	98.6	34.1	135.4	1.130	9.681	7.919	0.818	46.2	40.9	1 35	0.341
	10	3	64	22	98.6	36.2	137.9	1.170	10.189	8.548	0.839	48.9	41.8	1.35	0.355
	10	7	72	20	98.4	36.5	139.9	1.195	9.993	8.375	0.838	47.9	40.1	1.31	0.343

I.	7	6	79	..	98.5	24.0	130.2	0.945	8.341	7.232	0.867	40.3	42.7	1.68	0.310
F	8	9	78	20	98.9	26.8	140.0	1.040	9.241	7.642	0.827	44.2	42.5	1.65	0.316
10/16/25	9	4	67	24	98.2	29.5	143.0	1.110	9.305	7.918	0.851	44.8	40.3	1.52	0.313
	9	7	64	24	97.8	30.8	144.8	1.135	9.329	7.622	0.817	44.5	39.2	1.45	0.307
	10	1	64	20	98.2	33.3	149.1	1.200	10.539	8.895	0.844	50.6	42.2	1.52	0.340
	10	4	66	15	97.4	34.9	151.8	1.240	10.677	8.776	0.822	51.0	41.1	1.46	0.336
Q.	7	8	102	..	99.3	28.2	135.3	1.035	10.458	8.848	0.846	50.3	48.6	1.78	0.372
F	7	9	83	..	98.4	28.0	135.0	1.030	10.508	8.690	0.827	50.3	48.8	1.80	0.372
6/29/24	7	9	82	..	97.8	28.0	135.0	1.030	10.292	8.800	0.855	49.6	48.2	1.77	0.367
	8	0	76	..	98.7	29.9	137.8	1.075	10.279	8.861	0.862	49.6	46.2	1.66	0.360
	8	8	80	..	98.4	30.7	140.5	1.105	10.753	9.334	0.868	52.0	47.0	1.69	0.370
	10	7	80	15	97.8	39.9	152.0	1.310	10.936	9.601	0.878	53.0	40.5	1.33	0.349
	10	8	75	16	98.2	41.3	153.2	1.330	11.181	9.717	0.869	54.1	40.7	1.31	0.353
	11	3	84	16	98.0	45.5	157.6	1.425	12.525	11.072	0.884	60.8	42.7	1.34	0.386
32	8	1	66	..	98.3	27.2	128.9	0.985	9.514	7.392	0.777	44.9	45.6	1.65	0.348
F	8	6	84	..	98.5	28.1	133.4	1.025	9.116	7.858	0.862	44.0	42.9	1.57	0.330
1/4/24	8	9	74	..	98.4	29.5	135.2	1.055	9.200	7.995	0.869	44.5	42.2	1.51	0.329
	9	0	80	..	98.4	31.3	137.2	1.095	10.911	9.198	0.843	52.4	47.9	1.67	0.382
	9	3	68	..	98.0	33.1	140.0	1.140	11.208	9.449	0.843	53.8	47.2	1.63	0.385
	9	6	72	..	98.2	33.1	142.9	1.160	10.416	8.925	0.857	50.2	43.3	1.52	0.351
	9	9	74	..	98.4	35.0	145.4	1.210	10.593	9.396	0.887	51.5	42.5	1.47	0.354
	11	1	78	17	98.0	43.2	154.1	1.370	11.359	10.098	0.889	55.2	40.3	1.28	0.358
33	9	4	60	..	98.7	34.9	135.2	1.140	9.310	7.913	0.850	44.8	39.3	1.28	0.331
F	9	8	58	..	98.2	36.1	137.2	1.170	9.074	7.939	0.875	44.0	37.6	1.22	0.320
2/15/23	9	11	58	..	98.2	35.8	138.4	1.170	9.253	8.013	0.866	44.7	38.2	1.25	0.323
	10	2	58	..	98.4	37.3	139.2	1.200	9.228	7.890	0.855	44.5	37.1	1.19	0.319
	10	8	64	..	98.3	39.5	142.8	1.250	10.236	8.885	0.868	49.5	39.6	1.25	0.347
	11	10	54	17	97.8	47.2	149.9	1.400	10.726	9.792	0.913	52.5	37.5	1.11	0.350
	12	2	60	21	98.3	50.1	152.7	1.450	11.342	9.822	0.866	54.8	37.8	1.09	0.359
	12	5	54	19	98.0	51.4	153.2	1.465	11.820	10.083	0.853	56.9	38.9	1.11	0.372
	12	10	58	16	98.0	54.7	156.7	1.530	12.110	10.027	0.828	57.9	37.9	1.06	0.370
11	9	6	82	..	97.4	27.2	139.1	1.040	9.612	7.863	0.818	45.9	44.1	1.69	0.330
F	10	1	84	..	98.4	29.3	144.3	1.105	9.517	7.661	0.805	45.3	41.0	1.54	0.314
8/10/22	10	4	74	..	98.2	29.5	145.8	1.120	9.778	8.722	0 892	47.6	42.5	1.61	0.326
	12	4	86	19	97.8	34.7	157.0	1.265	9.939	8.249	0.830	47.6	37.6	1.37	0.303
	12	7	78	22	98.2	35.9	158.5	1.290	10.103	8.901	0 881	49.0	38.0	1.37	0.309
	12	11	74	22	....	37.5	160.3	1.330	10.380	8.647	0.833	49.7	37.4	1.33	0.310
8, F	10	6	80	..	98.8	34.0	140.3	1.160	10.150	9.256	0.912	49.6	42.8	1.46	0.354
4/27/22															
D.	11	11	74	..	97.9	44.2	162.8	1.440	11.821	10.462	0.885	57.4	39.9	1.30	0.353
F	12	2	76	14	98.0	46.8	164.7	1.490	12.324	10.968	0.890	59.9	40.2	1.28	0.364
1/20/23	12	11	76	20	97.4	50.3	168.5	1.555	12.844	10.481	0.816	61.3	39.4	1.22	0.364

ever, the computations were made, not only for the purpose of deciding with which measurement it is best to compare the heat production and determine the range of normal variation but also as the first step in determining what is the least number of normal persons it is necessary to study to obtain a representative sample of all normal persons in a physiologic study of this type. The latter is a question which, if satisfactorily answered, would eliminate the drawing of conclusions from too few data and would also eliminate the collection of unnecessary additional data. It is believed that sufficient data will have been collected to warrant the drawing of final conclusions only when insignificant changes in the values of the mean and the standard deviation are made with the addition of more data.

The results of the statistical analysis are presented in tables 12 to 16, inclusive. The divisions of 2 Kg. of body weight, 0.07 square meters of body surface and 6 cm. of height were made to divide the entire data into approximately the same number of groups for weight, body surface and height as were obtained when age groups of one year were used. Computations were not made on groups of data containing the results of less than 10 tests. It may be seen that the mean coefficients of variation are approximately the same for calories per hour compared to weight, for calories per hour compared to body surface and for calories per hour per square meter of body surface compared to age, and that the values obtained by the other methods are relatively higher.

Scatter diagrams in which calories per hour are plotted against body weight, body surface and total height, respectively, and also scatter diagrams in which calories per hour per square meter are plotted against age are given in figures 4 to 11, inclusive. Although the data indicate that for children of from 2 to 12 years old, inclusive, height is not as good a measure with which to compare the heat production as the others mentioned, the scatter diagram for calories in relation to height is presented in order that it may be available for comparison with the values presented by other workers. The straight line indicating the trend of the production of calories per hour per square meter of body surface in relation to age (figs. 4 and 5) and the line indicating the trend of the production of calories per hour in relation to height (figs. 10 and 11) were obtained by the weighted semiaverage method. The curves for the other graphs (figs. 6 to 9, inclusive) were fitted by inspection from the weighted means. The range of two plus and minus standard deviations from the weighted mean is indicated on the graphs by unsmoothed lines. The fitted curves show that the relationship of the calories per hour per square meter of body surface to age and that of the calories per hour to standing height are linear, while the relationship of the calories per hour to weight and that of the calories per hour to body

TABLE 12.—*Results of Statistical Analysis of 366 Basal Metabolism Tests on 52 Boys Between the Ages of 2 and 12 Years, Inclusive (Analysis of Calories per Hour, Calories per Hour per Square Meter, Calories per Hour per Kilogram and Calories per Hour per Centi-*

TABLE 12.—*Results of Statistical Analysis of 366 Basal Metabolism Tests on 52 Boys Between the Ages of 2 and 12 Years, Inclusive (Analysis of Calories per Hour, Calories per Hour per Square Meter, Calories per Hour per Kilogram and Calories per Hour per Centimeter, Respectively, Referred to Age for Boys)*

Age, Yr.	Calories per Hour			Calories per Hour per Square Meter			Calories per Hour per Kilogram			Calories per Hour per Centimeter		
	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage
2- 3	31.8±0.37	1.97±0.26	6.2	54.0±0.55	2.93±0.39	5.4	2.30±0.030	0.156±0.021	6.8	0.341±0.0035	0.0186±0.0025	5.5
3- 4	35.0±0.37	2.23±0.26	6.4	52.7±0.47	2.83±0.33	5.4	2.17±0.026	0.154±0.018	7.1	0.348±0.0030	0.0181±0.0021	5.2
4- 5	37.4±0.37	2.34±0.26	6.3	51.2±0.45	2.82±0.31	5.5	2.09±0.023	0.144±0.016	6.9	0.345±0.0030	0.0189±0.0021	5.5
5- 6	39.8±0.46	3.27±0.32	8.2	50.4±0.36	2.60±0.26	5.2	2.05±0.022	0.155±0.015	7.6	0.347±0.0028	0.0202±0.0020	5.8
6- 7	42.4±0.60	3.65±0.42	8.6	48.7±0.39	2.38±0.28	4.9	1.93±0.027	0.162±0.019	8.4	0.347±0.0034	0.0209±0.0024	6.0
7- 8	45.1±0.85	4.91±0.60	10.9	48.2±0.58	3.32±0.41	6.9	1.85±0.029	0.169±0.021	9.1	0.354±0.0054	0.0308±0.0038	8.7
8- 9	46.4±0.60	3.72±0.43	8.0	46.3±0.53	3.25±0.37	7.0	1.71±0.031	0.194±0.022	11.3	0.352±0.0039	0.0241±0.0028	6.8
9-10	48.4±0.65	3.86±0.46	8.0	45.4±0.57	3.40±0.41	7.5	1.63±0.033	0.197±0.023	12.0	0.356±0.0041	0.0243±0.0029	6.8
10-11	49.4±0.64	3.77±0.45	7.6	44.5±0.52	3.06±0.37	6.9	1.59±0.025	0.150±0.018	9.4	0.353±0.0041	0.0244±0.0029	6.9
11-12	49.1±1.45	4.58±1.03	9.3	41.7±0.59	1.88±0.42	4.5	1.49±0.028	0.089±0.020	6.0	0.336±0.0079	0.0250±0.0056	7.5
12-13	53.5±1.97	6.83±1.39	12.8	41.7±0.76	2.64±0.54	6.3	1.41±0.030	0.103±0.021	7.3	0.352±0.0098	0.0340±0.0069	9.6
		Mean	8.4		Mean	6.0		Mean	8.4		Mean	6.8

TABLE 13.—*Results of Statistical Analysis of 271 Basal Metabolism Tests on 41 Girls Between the Ages of 2 and 12 Years, Inclusive (Analysis of Calories per Hour, Calories per Hour per Square Meter, Calories per Hour per Kilogram and Calories per Hour per Centimeter, Respectively, Referred to Age for Girls)*

Age, Yr.	Calories per Hour			Calories per Hour per Square Meter			Calories per Hour per Kilogram			Calories per Hour per Centimeter		
	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage
2- 3	29.5±0.34	2.13±0.24	7.2	51.7±0.33	2.09±0.24	4.0	2.25±0.019	0.118±0.013	5.2	0.320±0.0031	0.0196±0.0022	6.1
3- 4	32.7±0.37	2.42±0.26	7.4	50.6±0.34	2.20±0.24	4.4	2.16±0.023	0.152±0.017	7.1	0.326±0.0027	0.0172±0.0019	5.3
4- 5	35.0±0.47	2.72±0.33	7.8	49.4±0.45	2.60±0.32	5.3	2.05±0.031	0.180±0.022	8.8	0.327±0.0033	0.0194±0.0023	5.9
5- 6	37.6±0.57	3.19±0.41	8.5	48.1±0.48	2.69±0.34	5.6	1.96±0.030	0.167±0.021	8.5	0.330±0.0034	0.0190±0.0024	5.8
6- 7	40.8±0.61	3.42±0.43	8.4	46.6±0.39	2.16±0.27	4.6	1.83±0.030	0.169±0.021	9.2	0.335±0.0034	0.0188±0.0024	5.6
7- 8	43.0±0.85	4.31±0.60	10.0	45.2±0.45	2.28±0.32	5.1	1.72±0.026	0.135±0.019	7.8	0.335±0.0041	0.0212±0.0029	6.3
8- 9	45.2±0.51	2.40±0.36	5.3	44.1±0.62	2.93±0.44	6.6	1.62±0.036	0.167±0.025	10.3	0.339±0.0034	0.0158±0.0024	4.7
9-10	47.0±0.91	3.54±0.65	7.5	42.1±0.76	2.93±0.53	7.0	1.47±0.041	0.158±0.029	10.7	0.340±0.0056	0.0217±0.0040	6.4
10-11	49.3±0.88	2.79±0.62	5.7	40.9±0.48	1.53±0.34	3.7	1.39±0.040	0.126±0.028	9.1	0.340±0.0043	0.0137±0.0031	4.0
11-12*	.....	.....	...	.....	.....	...	.....	.....	...	.....	.....	...
12-13*	.....	.....	...	.....	.....	...	.....	.....	...	.....	.....	...
		Mean	7.5		Mean	5.1		Mean	8.5		Mean	5.6

* Results not computed if less than 10 tests were made for group.

surface are somewhat more complex. The last two curves show similar trends and are of the type generally known as the typical growth curve; i. e., the slope of the line is greater in the region of the smaller weights

TABLE 14.—*Results of Statistical Analysis of 366 Basal Metabolism Tests on 52 Boys and of 271 Basal Metabolism Tests on 41 Girls Between the Ages of 2 and 12 Years, Inclusive (Analysis of Calories per Hour Referred to Weight)*

Boys, Calories per Hour				Girls, Calories per Hour			
Weight, Kg.	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Weight, Kg.	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage
12-13	30.9±0.44	1.65±0.31	5.3	10-11*	.....	.....	...
14-15	33.6±0.37	2.08±0.26	6.2	12-13	29.8±0.30	1.69±0.21	5.7
16-17	36.5±0.25	1.82±0.18	5.0	14-15	32.2±0.21	1.36±0.15	4.2
18-19	38.7±0.35	2.31±0.25	6.0	16-17	35.1±0.31	1.82±0.22	5.2
20-21	41.1±0.44	2.28±0.31	5.5	18-19	36.8±0.34	1.55±0.24	4.2
22-23	43.5±0.38	2.23±0.27	5.1	20-21	39.2±0.50	2.40±0.35	6.1
24-25	45.9±0.47	2.48±0.33	5.4	22-23	41.1±0.53	2.33±0.38	5.7
26-27	45.8±0.49	2.58±0.34	5.6	24-25	42.5±0.59	2.04±0.42	4.8
28-29	47.5±0.55	3.19±0.39	6.7	26-27	44.7±0.30	1.24±0.21	2.8
30-31	48.8±1.04	3.88±0.73	7.9	28-29	47.0±0.69	2.49±0.49	5.3
32-33	50.0±1.01	3.66±0.72	7.3	30-31*	.....	.....	...
34-35	51.4±0.96	3.60±0.68	7.0	32-33*	.....	.....	...
				34-35	47.6±0.81	2.43±0.57	5.1
Mean			6.1	Mean			4.9

* Results not computed if less than 10 tests were made for group.

TABLE 15.—*Results of Statistical Analysis of 366 Basal Metabolism Tests on 52 Boys and of 271 Basal Metabolism Tests on 41 Girls Between the Ages of 2 and 12 Years, Inclusive (Analysis of Calories per Hour Referred to Height)*

Boys, Calories per Hour				Girls, Calories per Hour			
Height, Cm.	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Height, Cm.	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage
86- 92	31.1±0.56	2.03±0.40	6.5	84- 90	28.3±0.66	2.48±0.47	8.8
93- 99	33.1±0.36	2.00±0.26	6.0	91- 97	30.5±0.30	1.77±0.21	5.8
100-106	36.2±0.32	1.92±0.23	5.3	98-104	32.9±0.28	1.84±0.20	5.6
107-113	37.9±0.32	2.20±0.23	5.8	105-111	36.1±0.36	2.02±0.25	5.6
114-120	40.6±0.37	2.49±0.26	6.1	112-118	37.8±0.39	2.07±0.28	5.5
121-127	43.7±0.42	2.95±0.30	6.7	119-125	41.2±0.50	2.44±0.35	5.9
128-134	46.5±0.38	2.61±0.27	5.6	126-132	43.9±0.40	2.20±0.28	5.0
135-141	49.0±0.65	4.53±0.46	9.2	133-139	46.6±0.55	2.72±0.39	5.8
142-148	50.3±0.76	4.29±0.54	8.5	140-146	47.9±0.86	3.11±0.61	6.5
149-155*	.....	.....	...	147-153*	.....	.....	...
				154-160*	.....	.....	...
Mean			6.6	Mean			6.1

* Results not computed if less than 10 tests were made for group.

and body surfaces than it is in that of the larger ones. The comparison of these trends with those of the other physiologic measurements of the children will no doubt lead to many interesting observations in the future.

By reference to tables 12 to 16, inclusive, and to figures 4 to 11, inclusive, it can be seen that the portions of the scatter charts included within the plus and minus two standard deviations from the mean, i. e., the region including 95 per cent of the tests, denote approximately ±11

TABLE 16.—*Results of Statistical Analysis of 366 Basal Metabolism Tests on 52 Boys and of 271 Basal Metabolism Tests on 41 Girls Between the Ages of 2 and 12 Years, Inclusive (Analysis of Calories per Hour Referred to Body Surface)*

Boys, Calories per Hour				Girls, Calories per Hour			
Body Surface, Sq. M.	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Thereof	Coefficient of Variation, Percentage	Body Surface, Sq. M.	Mean ± Standard Error Thereof	Standard Deviation ± Standard Error Therof	Coefficeint of Variation, Percentage
0.520-0.580	31.0 ± 0.45	1.73 ± 0.31	5.6	0.470-0.540*			
0.590-0.650	33.3 ± 0.38	2.01 ± 0.27	6.1	0.550-0.610	30.3 ± 0.26	1.53 ± 0.18	5.1
0.660-0.720	36.1 ± 0.25	1.73 ± 0.18	4.8	0.620-0.680	32.5 ± 0.25	1.59 ± 0.18	4.9
0.730-0.790	38.4 ± 0.29	1.95 ± 0.20	5.1	0.690-0.750	35.5 ± 0.30	1.78 ± 0.21	5.0
0.800-0.860	41.2 ± 0.37	2.36 ± 0.26	5.7	0.760-0.820	37.3 ± 0.39	1.96 ± 0.28	5.2
0.870-0.930	43.7 ± 0.41	2.53 ± 0.29	5.8	0.830-0.890	40.2 ± 0.41	2.05 ± 0.29	5.1
0.940-1.000	46.1 ± 0.41	2.53 ± 0.29	5.5	0.900-0.960	42.7 ± 0.52	2.14 ± 0.37	5.0
1.010-1.070	46.8 ± 0.55	3.28 ± 0.39	7.0	0.970-1.030	45.1 ± 0.47	2.36 ± 0.33	5.2
1.080-1.140	48.7 ± 0.66	3.70 ± 0.47	7.6	1.040-1.100	47.0 ± 0.84	2.92 ± 0.60	6.2
1.150-1.210	50.4 ± 0.93	3.95 ± 0.66	7.8	1.110-1.170	47.2 ± 0.76	2.73 ± 0.54	5.8
1.220-1.280	54.1 ± 0.73	2.41 ± 0.51	4.5				
Mean.....			6.0	Mean.....			5.3

* Results not computed if less than 10 tests were made for group.

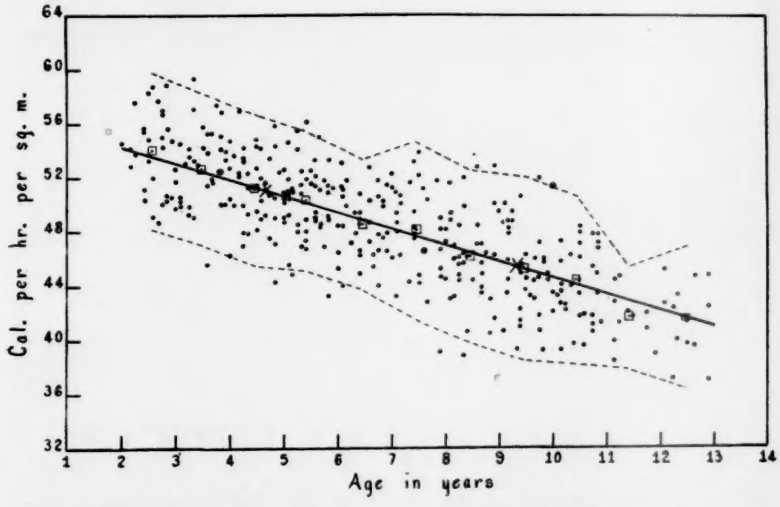

Fig. 4.—Scatter diagram of the results of 366 basal metabolism tests on 52 boys expressed as calories per hour per square meter of body surface referred to age. The central trend line (unbroken line) was fitted by the weighted semi-average method (x = points determined). A dot enclosed by a square indicates the weighted mean for the age panel. The region between the broken lines is that included within plus and minus two standard deviations from the means.

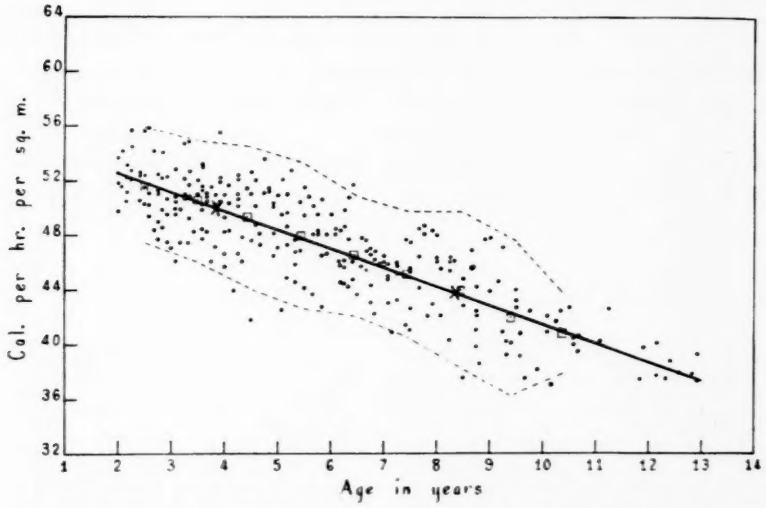

Fig. 5.—Scatter diagram of the results of 271 basal metabolism tests on 41 girls expressed as calories per hour per square meter of body surface referred to age. The central trend line (unbroken line) was fitted by the weighted semi-average method (x = points determined). A dot enclosed by a square indicates the weighted mean for the age panel. The region between the broken lines is that included within plus and minus two standard deviations from the means.

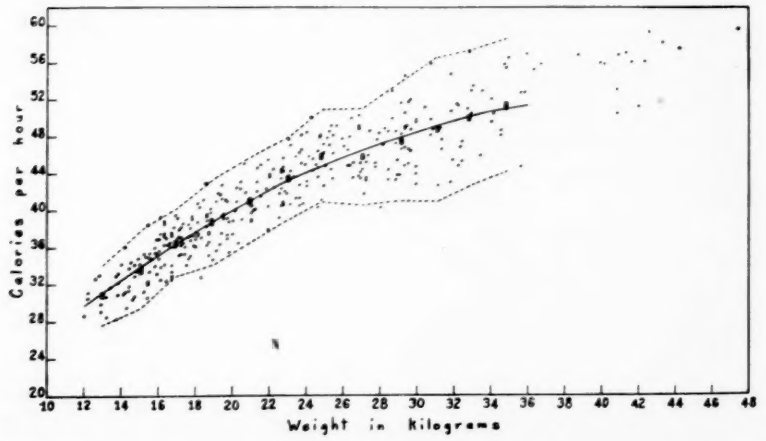

Fig. 6.—Scatter diagram of the results of 365 basal metabolism tests on 52 boys expressed as calories per hour referred to weight. The central trend line (unbroken line) was fitted by inspection from the weighted means (dot enclosed by a square). The region between the broken lines is that included within plus and minus two standard deviations from the means. The result of the last test on subject no. 14 is not included in this chart.

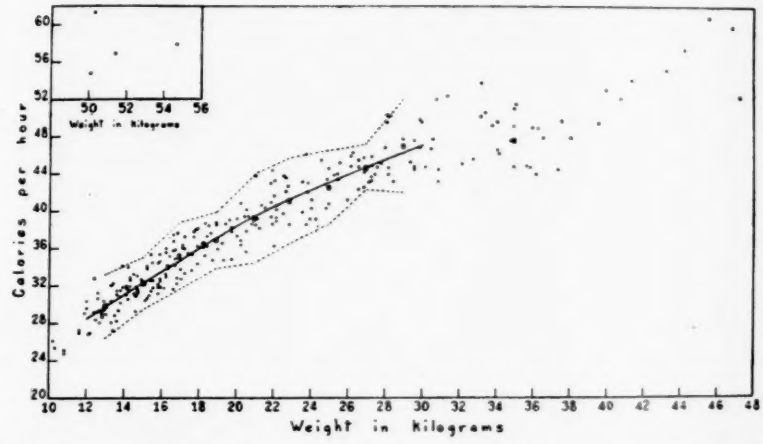

Fig. 7.—Scatter diagram of the results of 271 basal metabolism tests on 41 girls expressed as calories per hour referred to weight. The central trend line (unbroken line) was fitted by inspection from the weighted means (dot enclosed by a square). The region between the broken lines is that included within plus and minus two standard deviations from the means.

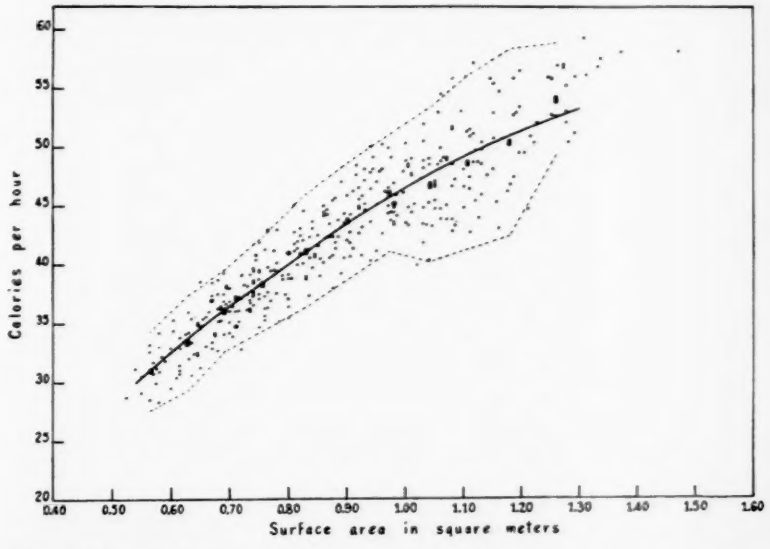

Fig. 8.—Scatter diagram of the results of 366 basal metabolism tests on 52 boys expressed as calories per hour referred to body surface. The central trend line (unbroken line) was fitted by inspection from the weighted means (dot enclosed by a square). The region between the broken lines is that included within plus and minus two standard deviations from the means.

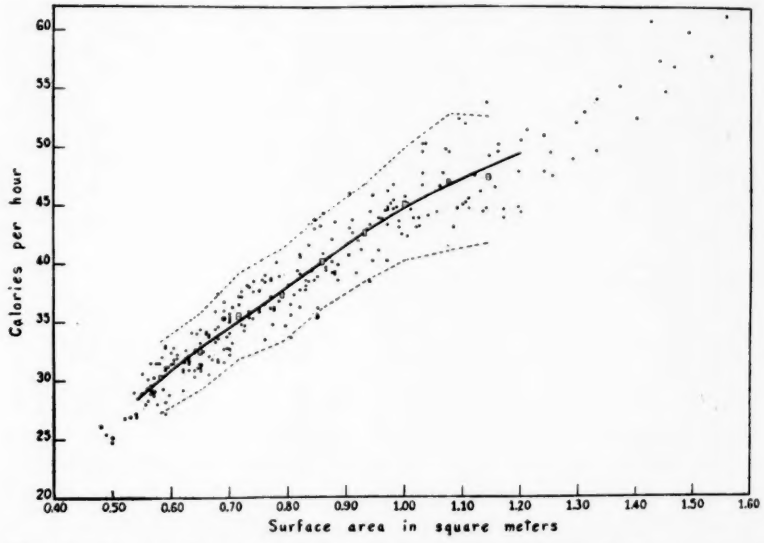

Fig. 9.—Scatter diagram of the results of 271 basal metabolism tests on 41 girls expressed as calories per hour referred to body surface. The central trend line (unbroken line) was fitted by inspection from the weighted means (dot enclosed by a square). The region between the broken lines is that included within plus and minus two standard deviations from the means.

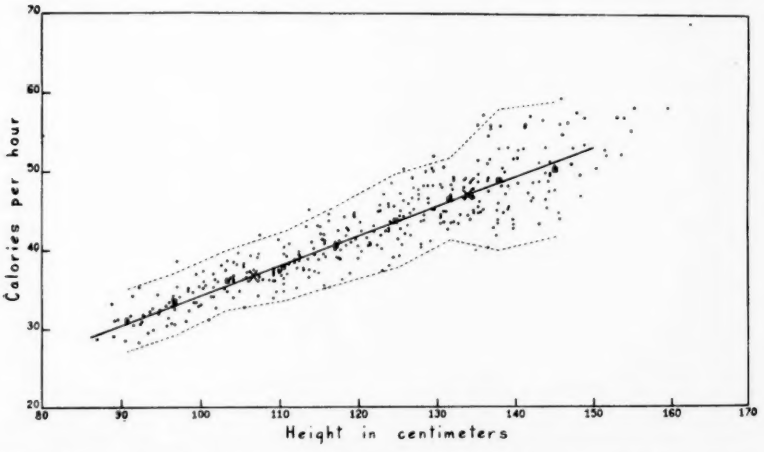

Fig. 10.—Scatter diagram of the results of 366 basal metabolism tests on 52 boys expressed as calories per hour referred to height. The central trend line (unbroken line) was fitted by the weighted semiaverage method (x = points determined). A dot enclosed by a square indicates the weighted mean for the height panel. The region between the broken lines is that included within plus and minus two standard deviations from the means.

per cent variation from the mean for the girls and ±12 per cent for the boys for the following three methods of representing heat production: calories per hour per square meter of body surface in relation to age, calories per hour in relation to weight and calories per hour in relation to body surface. Those portions represent a ±12 and ±13 per cent variation from the mean for girls and boys, respectively, for the method which expresses basal heat production in relation to height. The approximate percentage deviation from the mean represented by plus and minus three standard deviations from the mean, which includes 99.7 per cent of the tests, is ±16 and ±18 per cent for girls and boys, respectively, for the first three methods mentioned, and ±18 and ±20 per cent for girls and boys, respectively, for the last method mentioned.

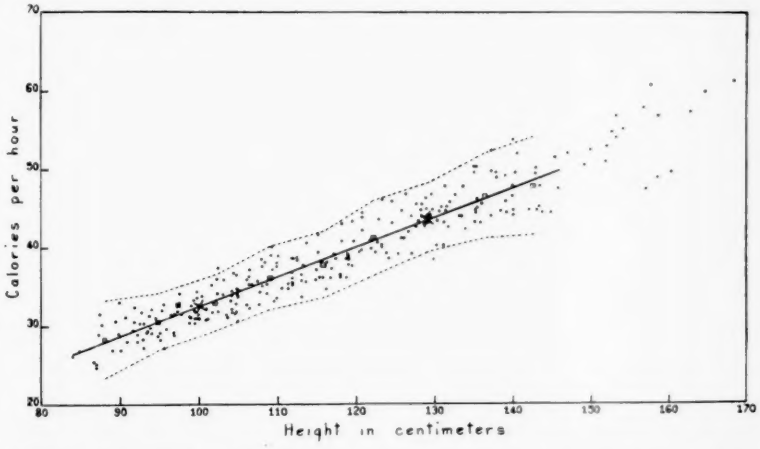

Fig. 11.—Scatter diagram of the results of 271 basal metabolism tests on 41 girls expressed as calories per hour referred to height. The central trend line (unbroken line) was fitted by the weighted semiaverage method (x = points determined). A dot enclosed by a square indicates the weighted mean for the height panel. The region between the unbroken lines is that included within plus and minus two standard deviations from the means.

The values given as percentage deviations from the mean of two and of three standard deviations from the mean were obtained by multiplying the mean coefficient of variation, which expresses the standard deviation in terms of percentage variation from the mean, by 2 and 3, respectively. It is obvious from tables 12 to 16, inclusive, that the coefficient of variation of single panels of the arbitrary divisions of age, weight, height and body surface vary somewhat and that the mean coefficient of variation, therefore, gives only an approximate value for the percentage variation through the entire extent of the graph.

The values of the smoothed central trend lines of figures 4 to 11, inclusive, are presented in tables 17 to 20, inclusive. Except in the chart involving age the curves were not extended to include all the points

TABLE 17.—*Central Trend Line Values for Calories per Hour per Square Meter of Body Surface (Du Bois and Du Bois [84] Height-Weight Formula, with Constant 71.84) in Relation to Age for Boys and Girls Between the Ages of 2 and 12 Years, Inclusive*

Age, Years	Calories per Hour per Sq. M.		Age, Years	Calories per Hour per Sq. M.	
	Boys	Girls		Boys	Girls
2.00	54.3	52.6	7.75	47.4	44.7
2.25	54.0	52.3	8.00	47.1	44.3
2.50	53.7	51.9	8.25	46.8	44.0
2.75	53.4	51.6	8.50	46.5	43.7
3.00	53.1	51.2	8.75	46.2	43.4
3.25	52.8	50.9	9.00	45.9	43.0
3.50	52.5	50.5	9.25	45.6	42.7
3.75	52.2	50.2	9.50	45.3	42.3
4.00	51.9	49.8	9.75	45.0	42.0
4.25	51.6	49.5	10.00	44.7	41.6
4.50	51.3	49.2	10 25	44.4	41.3
4.75	51.0	48.9	10.50	44.1	40.9
5.00	50.7	48.5	10.75	43.8	40.6
5.25	50.4	48.2	11.00	43.5	40.2
5.50	50.1	47.8	11.25	43.2	39.9
5.75	49.8	47.5	11.50	42.9	39.5
6.00	49.5	47.1	11.75	42.6	39.2
6.25	49.2	46.8	12.00	42.3	38.8
6.50	48.9	46.4	12.25	42.0	38.5
6.75	48.6	46.1	12.50	41.7	38.1
7.00	48.3	45.7	12.75	41.4	37.8
7.25	48.0	45.4	13.00	41.1	37.4
7.50	47.7	45.0			

TABLE 18.—*Central Trend Line Values for Calories per Hour in Relation to Weight for Boys and Girls*

Weight, Kg.	Calories per Hour		Weight, Kg.	Calories per Hour	
	Boys	Girls		Boys	Girls
12.0	29.7	28.0	24.5	44.6	42.6
12.5	30.4	29.1	25.0	45.0	43.0
13.0	31.2	29.7	25.5	45 4	43.4
13.5	31.9	30.4	26.0	45.8	43.8
14.0	32.5	31.0	26.5	46.2	44.3
14.5	33.2	31.6	27.0	46.6	44.7
15.0	33.9	32.2	27.5	47.0	45.1
15.5	34.6	32.9	28.0	47.3	45.5
16.0	35.2	33.5	28.5	47.6	46.0
16.5	35.8	34.1	29.0	47.9	46.4
17.0	36.5	34.7	29.5	48.2	46.7
17.5	37.1	35.4	30.0	48.5	47.0
18.0	37.7	36.0	30.5	48.8	
18.5	38.3	36.6	31.0	49.1	
19.0	38.8	37.2	31.5	49.4	
19.5	39.4	37.8	32.0	49.7	
20.0	40.0	38.4	32.5	49.9	
20.5	40.6	39.0	33.0	50.2	
21.0	41.2	39.5	33.5	50.5	
21.5	41.8	40.0	34.0	50.7	
22.0	42.3	40.4	34.5	50.9	
22.5	42.8	40.9	35.0	51.1	
23.0	43.3	41.3	35.5	51.3	
23.5	43.7	41.8	36.0	51.5	
24.0	44.1	42.2			

on the charts, since the points became much too scattered, especially in the case of the larger children, to warrant the extension of the lines throughout the whole graph. With the exception of the chart showing

calories per hour per square meter in relation to age for girls, the curves were confined to those arbitrary divisions of the abscissa which contain at least 10 tests each. All four of the methods of correlation gave higher values for boys than for girls. This relationship is shown in figure 12.

TABLE 19.—*Central Trend Line Values for Calories per Hour in Relation to Body Surface (Du Bois and Du Bois[84] Height-Weight Formula, with Constant 71.84) for Boys and Girls*

Body Surface, Sq. M.	Calories per Hour		Body Surface, Sq. M.	Calories per Hour	
	Boys	Girls		Boys	Girls
0.540	29.9	28.4	0.940	44.8	43.0
0.560	30.8	29.3	0.960	45.4	43.7
0.580	31.6	30.1	0.980	46.0	44.3
0.600	32.5	30.9	1.000	46.6	44.9
0.620	33.4	31.7	1.020	47.1	45.4
0.640	34.2	32.5	1.040	47.7	45.9
0.660	35.0	33.2	1.060	48.2	46.4
0.680	35.8	33.9	1.080	48.8	46.9
0.700	36.5	34.6	1.100	49.3	47.4
0.720	37.2	35.3	1.120	49.8	47.8
0.740	37.9	36.0	1.140	50.2	48.2
0.760	38.6	36.7	1.160	50.6	48.7
0.780	39.3	37.4	1.180	51.0	49.1
0.800	40.0	38.1	1.200	51.5	49.5
0.820	40.7	38.8	1.220	51.9	
0.840	41.4	39.5	1.240	52.3	
0.860	42.1	40.2	1.260	52.6	
0.880	42.8	40.9	1.280	53.0	
0.900	43.5	41.6	1.300	53.2	
0.920	44.2	42.3			

TABLE 20.—*Central Trend Line Values for Calories per Hour in Relation to Height for Boys and Girls*

Height, Cm.	Calories per Hour		Height, Cm.	Calories per Hour	
	Boys	Girls		Boys	Girls
84	....	26 4	118	41.1	39 3
86	....	27.1	120	41.8	40.1
88	29.8	27.9	122	42.6	40.8
90	30.5	28.6	124	43.3	41.6
92	31.2	29.4	126	44.1	42.3
94	32.0	30.1	128	44.8	43.1
96	32.7	30.9	130	45 6	43.8
98	33.5	31.7	132	46.3	44.6
100	34.2	32.4	134	47.1	45.3
102	35.0	33.2	136	47.8	46.1
104	35.8	34.0	138	48.6	46.9
106	36.5	34.7	140	49.4	47.6
108	37.3	35.5	142	50.1	48.4
110	38.0	36.3	144	50.8	49.2
112	38.8	37.0	146	51.6	49.9
114	39.6	37.8	148	52.4	
116	40.3	38.6	150	53.2	

The observed respiratory quotient for each satisfactory test was included in the individual data, and frequency tables (tables 21 and 22) showing the occurrence of the different respiratory quotients for the age groups and for the whole series were constructed for girls and boys separately. The charts also give the mean values for each age group and for the complete data. The mean values and the frequencies indi-

cate that for children of from 2 to 12 years of age, inclusive, there is no relationship between age and the height of the respiratory quotient and that the latter is not influenced by sex. The respiratory quotients

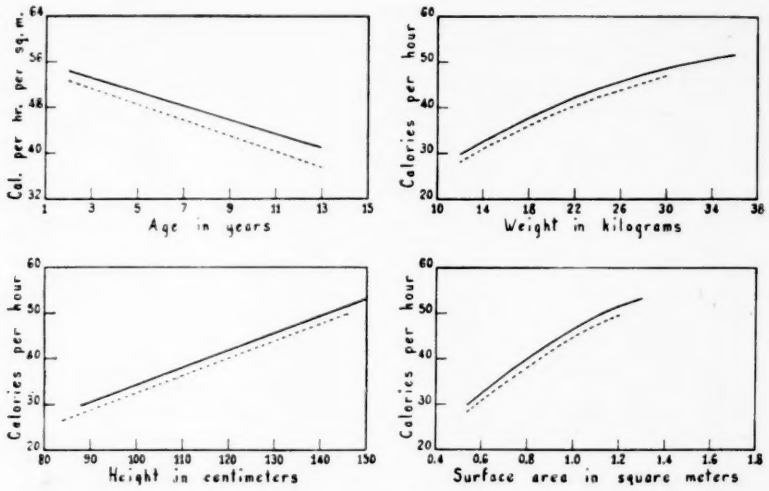

Fig. 12.—Graphic comparison of the trend lines (figs. 4 to 11, inclusive) for the boys and the girls of the present study. The boys are represented by the unbroken line and the girls by the broken line.

TABLE 21.—*Frequency Distribution in Relation to Age of 366 Determinations of the Respiratory Quotient on 52 Boys Between the Ages of 2 and 12 Years, Inclusive*

Respiratory Quotient	Age, Years										
	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	2-13
0.760-0.769	1	..	..	..	..	..	..	..	..	..	..	1
0.770-0.779	..	..	1	..	..	..	..	..	..	..	..	1
0.780-0.789	1	..	..	1	..	..	2	..	..	..	..	4
0.790-0.799	4	..	..	1	1	2	1	1	1	1	2	14
0.800-0.809	1	2	..	3	..	3	1	2	1	1	..	14
0.810-0.819	2	5	4	4	3	4	4	2	6	3	1	38
0.820-0.829	3	1	3	5	5	4	3	5	5	1	3	38
0.830-0.839	4	3	4	9	9	7	5	5	2	1	2	51
0.840-0.849	4	8	7	8	7	7	5	3	3	3	1	56
0.850-0.859	2	10	6	11	4	1	5	5	7	..	1	52
0.860-0.869	2	5	9	4	6	3	6	4	6	..	..	45
0.870-0.879	4	2	6	2	1	1	2	2	2	..	2	24
0.880-0.889	1	..	..	3	2	..	3	2	1	1	..	13
0.890-0.899	..	1	..	..	..	2	..	3	1	..	1	8
0.900-0.909	..	..	1	1	..	..	1	..	..	..	..	3
0.910-0.919	..	..	..	..	..	..	1	1	1	..	..	3
0.920-0.929	..	..	..	..	..	..	..	1	..	..	..	1
Average respiratory quotient	0.833	0.845	0.852	0.843	0.843	0.836	0.845	0.850	0.845	0.829	0.838	0.843

for the boys and girls taken together fall between 0.76 and 0.92, show greatest frequency at from 0.84 to 0.85 and give a mean value of 0.844. This mean corresponds to a calorific value of 4.805, if the assumption is made that 15 per cent of the total calories produced are derived from

the oxidation of protein (table 6). The figure 4.825, which is universally used in the computation of the heat production from the oxygen consumption as measured by the usual type of closed circuit apparatus varies by only +0.42 per cent from this figure.

Since no attempt was made in this study to regulate the diet of the children in any way, the respiratory quotients represent those of normal fasting children, i. e., children who had not eaten for at least twelve hours and who were on the usual diets of representative American families.

The variation of the respiratory quotients of a single subject may be observed from the values given in tables 10 and 11, but since this

TABLE 22.—*Frequency Distribution in Relation to Age of 271 Determinations of the Respiratory Quotient on 41 Girls Between the Ages of 2 and 12 Years, Inclusive*

	Age, Years											
Respiratory Quotient	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	2-13
0.760-0.769												
0.770-0.779	1	..	..	..	..	..	1	..	..	..	..	2
0.780-0.789	..	..	1	..	..	1	..	..	..	..	..	2
0.790-0.799	2	1	..	..	..	..	1	1	..	..	..	5
0.800-0.809	2	2	2	..	4	2	1	1	1	..	..	15
0.810-0.819	4	1	3	3	3	1	1	3	..	..	1	20
0.820-0.829	7	7	7	3	3	4	3	1	1	..	1	37
0.830-0.839	9	9	4	4	4	3	2	1	2	..	2	40
0.840-0.849	3	5	3	11	3	5	4	3	1	..	..	38
0.850-0.859	5	3	3	3	7	2	1	3	1	..	1	29
0.860-0.869	2	6	4	2	5	4	5	1	2	..	1	32
0.870-0.879	..	5	2	3	2	3	1	1	1	..	..	18
0.880-0.889	..	1	4	1	1	..	..	1	..	3	1	12
0.890-0.899	5	2	1	1	..	1	2	..	1	..	1	14
0.900-0.909	..	1	1	..	..	1	1	..	..	..	..	4
0.910-0.919	..	..	..	1	..	..	..	..	1	1	..	3
0.920-0.929												
Average respiratory quotient..	0.838	0.847	0.845	0.848	0.842	0.846	0.846	0.840	0.857	0.893	0.850	0.845

paper does not deal with the individual child, the respiratory quotients will not be discussed from that standpoint.

COMMENT

A detailed review of the literature reveals the fact that basal studies on the basal metabolism of approximately 2,000 normal children between the ages of 2 and 12 years, inclusive, have been reported and that, although in all these studies the experimental conditions were described as "basal" or "standard," some confusion still exists in regard to the status of prediction standards for the basal metabolism of children. In an attempt to resolve this confusion, rather than to add to it by publishing the results presented in the previous section of this paper as prediction standards without any attempt to show their relationship to the results of other workers, a minute analysis of the data reported in the literature in relation to the central trend values obtained in this

study has been made. Whenever it was possible with the information available, the percentage deviations from the values obtained in the present study were calculated, and to show the frequencies of the percentage deviations, histograms were constructed (figs. 13 to 17, inclusive). If complete individual or group data had not been published, the results given were compared with the values obtained in the present study in as complete a manner as possible. The mean percentage deviations of the results of each worker were computed both with regard to sign and without regard to sign. These values for girls and boys separately are given in table 23.

The results for some of the children between the ages of 2 and 12 years, inclusive, on whom basal metabolism tests have been reported in the literature cannot be compared with the values obtained in the present study in all four ways—calories per hour in relation to weight, height and body surface, respectively, and calories per hour per square meter of body surface in relation to age. The reason for this is that the weight, height or body surface, or any two, or even all three of these measurements, of a child between the ages mentioned may fall outside the range of the values for weight, height and body surface included in the central trend lines of the present study. This may occur at both ends of the range and is unavoidable, since the data do not warrant the extension of the trend lines beyond certain limits, as has been explained. The lower and the upper limit of the trend lines are: for weight, 12 and 30 Kg. for girls and 12 and 36 Kg. for boys; for height, 84 and 146 cm. for girls and 88 and 150 cm. for boys; for body surface, 0.54 and 1.20 square meters for girls and 0.54 and 1.30 square meters for boys (tables 17 to 20, inclusive). The histograms show the results only of the tests reported by the different workers that were found suitable for comparison by each method.

By reference to table 23 it can be seen that the data reported by Klein, Müller, and Steuber,[27] Blunt, Tilt, McLaughlin and Gunn,[39] Bierring,[42] Nylin,[51] Collins and McClendon [52] on boys and Nakagawa [61] on Japanese children show mean percentage deviations from the values presented in tables 17 to 20, inclusive, of less than ± 5 with regard to sign and of less than 8 without regard to sign for all four methods of expressing heat production. It should be noted that the subjects of Klein, Müller and Steuber were reported as asleep during the metabolism tests. The data reported by Magnus-Levy and Falk [7] for girls, MacLeod,[32] Göttche,[41] Lax and Petényi [45] and Wang, Kern, Frank and Hays [36] show mean percentage deviations with regard to sign of less than ± 5 and mean percentage deviations without regard to sign of less than 10 for the three methods of expressing heat production that do not involve age. The workers who have reported values higher

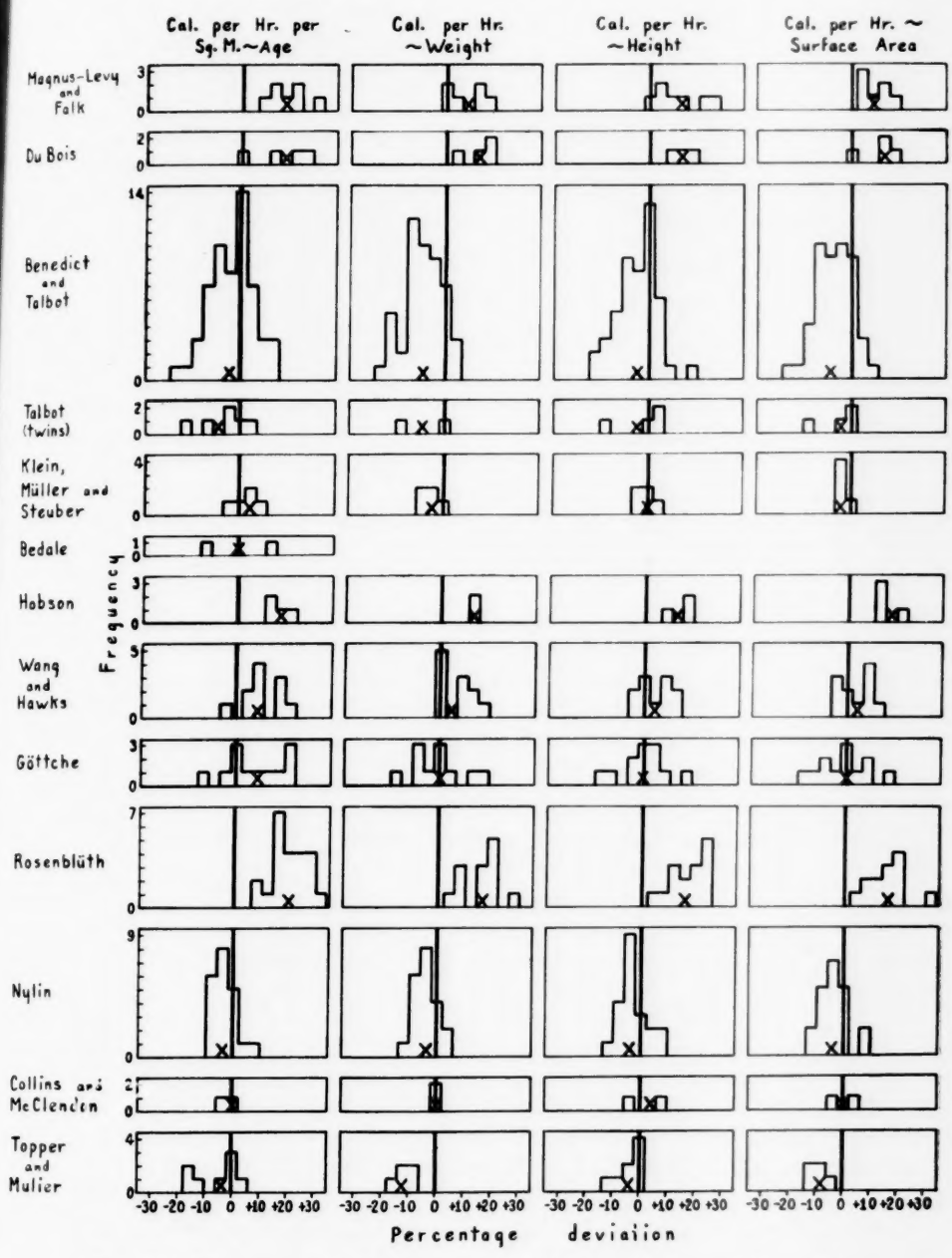

Fig. 13.—Histograms of the percentage deviations of the results on boys reported by the workers indicated on the chart from the central trend line values of the present study. × represents the mean percentage deviation with regard to sign.

than these are the following: Magnus-Levy and Falk [7] for boys, Du Bois,[12] Hobson,[29] Rosenblüth,[47] Klotz,[54] Wang and Hawks [37] for Chinese children, Collins and McClendon [52] for girls, Talbot [22] for twin

TABLE 23.—*Mean Percentage Deviations With and Without Regard to Sign of the Results of Various Workers Compared with Those of the Present Study*

Author	Sex	Calories per Hour per Square Meter Referred to Age		Calories per Hour Referred to Weight		Calories per Hour Referred to Height		Calories per Hour per Square Meter Referred to Body Surface	
		Without Regard to Sign	With Regard to Sign	Without Regard to Sign	With Regard to Sign	Without Regard to Sign	With Regard to Sign	Without Regard to Sign	With Regard to Sign
Magnus-Levy and Falk *†	M	16.5	+16.5	8.0	+ 8.0	10.4	+10.4	7.7	+ 7.7
	F	13.9	+13.9	7.4	+ 0.5	8.4	+ 1.4	8.1	— 0.4
Du Bois*‡	M	15.1	+15.1	11.7	+11.7	12.8	+12.8	10.1	+10.1
Benedict and Talbot	M	6.5	— 3.4	8.6	— 8.1	6.7	— 4.3	7.6	— 6.7
	F	9.8	— 7.6	12.6	—12.2	10.7	— 9.3	12.2	—11.6
Benedict and Hendry*§	F	8.3	— 8.3						
Benedict and Meyer (Chinese)	F	10.9	+10.9	....	.....	....	.....	11.0	— 0.2
Talbot (twins)	M	7.8	— 6.5	8.6	— 8.6	5.9	— 3.1	6.4	— 5.6
	F	20.7	+20.7	18.5	+18.5	19.4	+19.4	18.0	+18.0
Klein, Müller and Steuber*	M	3.8	+ 2.3	4.8	— 4.8	2.4	— 0.5	3.0	— 2.9
Bedale ‖	M	12.6	— 0.5						
	F	9.1	+ 9.1						
Hobson*	M	14.4	+14.4	13.4	+13.4	12.6	+12.6	14.6	+14.6
Macleod	F	11.3	+ 6.2	4.6	+ 1.3	7.0	+ 1.6	6.7	— 3.4
Wang, Kern, Frank and Hays *	F	8.6	+ 6.2	8.3	— 2.0	8.7	— 0.1	8.0	— 0.9
Wang and Hawks (Chinese)	M	10.3	+ 9.9	6.1	+ 5.5	5.8	+ 3.9	5.2	+ 3.1
	F	19.0	+19.0	10.1	+ 8.0	10.6	+10.3	8.6	+ 8.6
Wang	F	0.2	+ 0.2	6.9	— 6.9	7.2	— 7.2	4.2	— 4.2
Blunt, Tilt, McLaughlin and Gunn	F	7.2	+ 4.9	6.4	+ 0.2	6.3	+ 3.0	5.9	+ 1.3
Göttche *	M	9.6	+ 6.3	6.8	— 0.7	5.7	+ 0.3	7.1	— 0.3
	F	8.4	+ 6.8	9.7	— 0.2	9.8	+ 1.3	8.7	— 1.6
Lax and Petényi	F	11.8	+11.8	4.9	+ 0.5	5.9	+ 1.4	4.0	— 2.1
Rosenblüth *	M	20.0	+20.0	15.8	+15.8	17.4	+17.4	15.8	+15.8
Nylin *¶	M	4.5	— 3.0	4.7	— 3.7	4.8	— 2.4	5.1	— 3.5
	F	4.6	+ 1.1	4.6	— 1.2	4.4	+ 0.4	4.5	— 0.2
Collins and McClendon *	M	1.9	— 1.9	0.7	— 0.1	6.2	+ 3.1	3.9	+ 1.0
	F	7.4	+ 7.4	7.8	+ 7.8	13.4	+13.4	10.0	+10.0
Topper and Muller *	M	6.5	— 5.4	10.8	—10.8	3.4	— 3.4	9.2	— 9.2
	F	9.5	+ 6.9	7.6	— 7.6	7.9	+ 3.4	6.8	— 1.8
Bierring	M	5.5	+ 2.4	4.3	— 0.1	5.1	+ 0.5	4.6	— 0.4
Klotz *	M	14.4	+14.4	11.6	+11.2	13.5	+13.5	11.9	+11.8
	F	14.6	+14.6	10.2	+ 9.9	9.7	+ 9.1	8.9	+ 8.4
Molitch and Cousins	M	6.0	— 1.4						
Robb	M	8.1	+ 7.3	7.2	+ 6.0	9.4	+ 8.7	7.0	+ 6.3
	F	6.1	+ 5.9	7.9	+ 7.0	8.2	+ 8.2	6.8	+ 6.5
Nakagawa (Japanese)	M	6.8	+ 4.6	5.2	+ 0.4	5.6	— 0.1	5.5	— 0.5
	F	6.2	+ 5.0	4.7	+ 0.9	4.7	— 1.8	4.2	— 1.0

* Surface area calculated by the Du Bois and Du Bois [84] height-weight formula.
† Calorific values in table 8 used for observed respiratory quotient.
‡ Lowest value for a single hour.
§ Minimum values.
‖ Mean values.
¶ Calorific value of 4.825 for 1 liter of oxygen.

girls, and Robb.[59] The authors who have reported lower values are: Benedict and Talbot,[1] Talbot [22] for twin boys, Wang,[38] and Topper and Mulier [53] for boys.

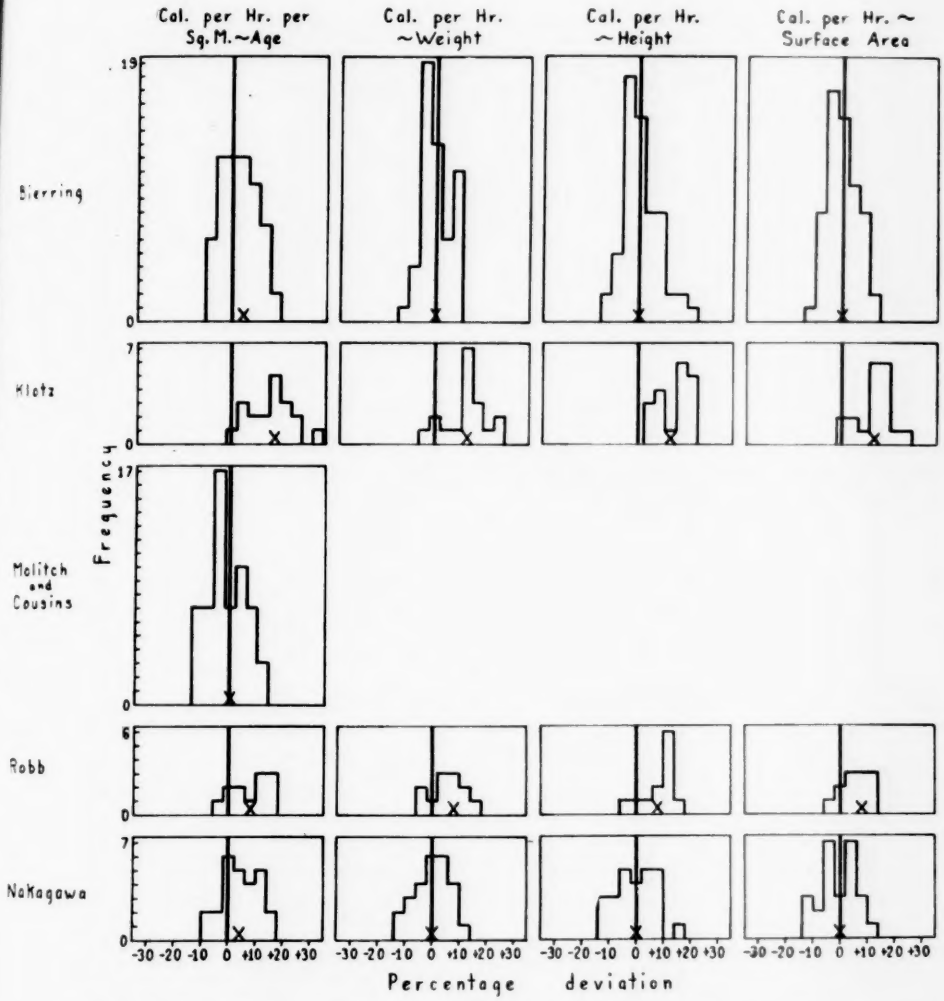

Fig. 14.—Histograms of the percentage deviations of the results on boys reported by the workers indicated on the chart from the central trend line values of the present study. × represents the mean percentage deviation with regard to sign.

The results of Molitch and Cousins [58] show close agreement with the values obtained in the present study by the one possible method of comparison, i. e., comparison of the calories per hour per square meter of body surface in relation to age. They show a mean percentage

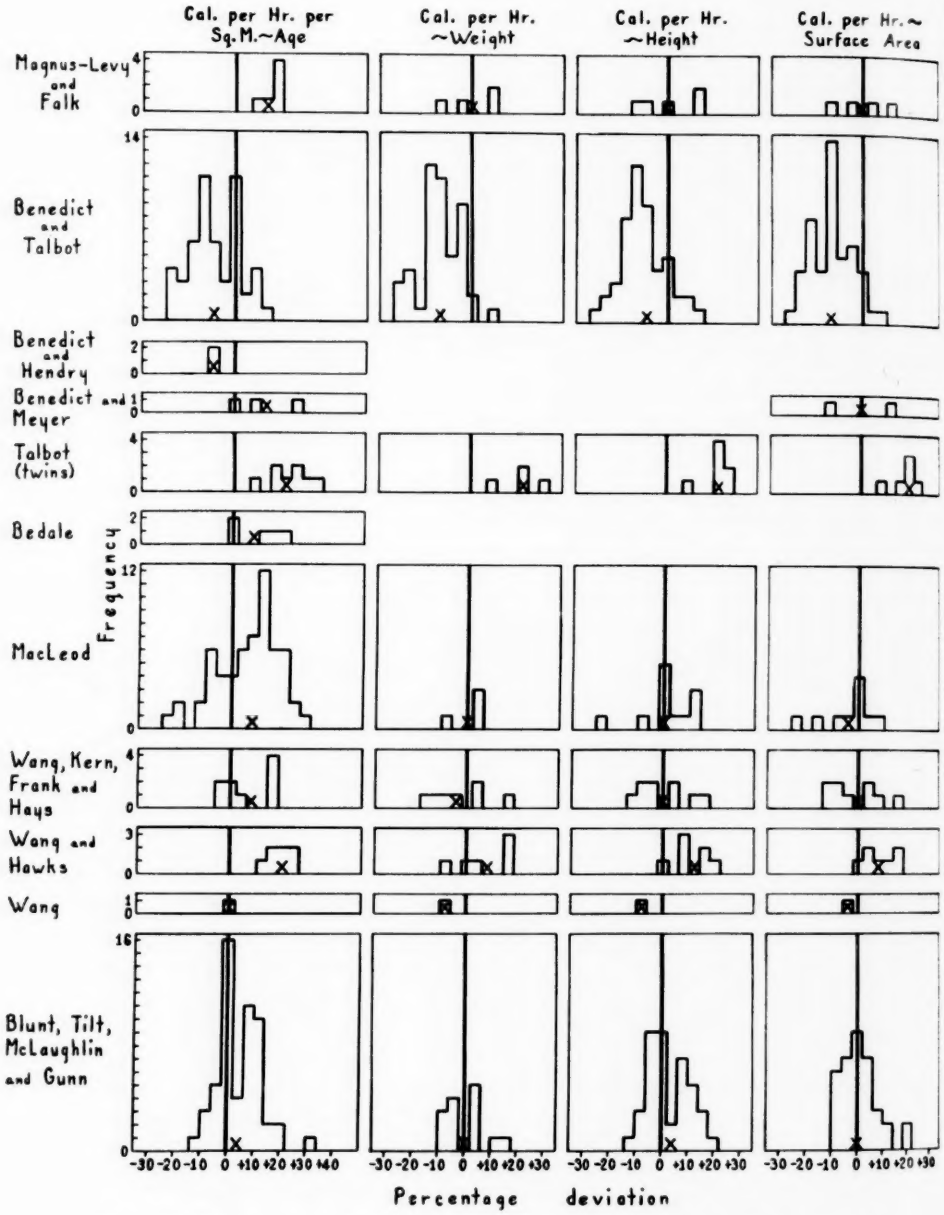

Fig. 15.—Histograms of the percentage deviations of the results on girls reported by the workers indicated on the chart from the central trend line values of the present study. × represents the mean percentage deviation with regard to sign.

deviation with regard to sign of —1.4 and without regard to sign of 6. It is necessary also to compare the results of Benedict and Hendry [18] and those of Bedale [28] by this method only. The values of Benedict and

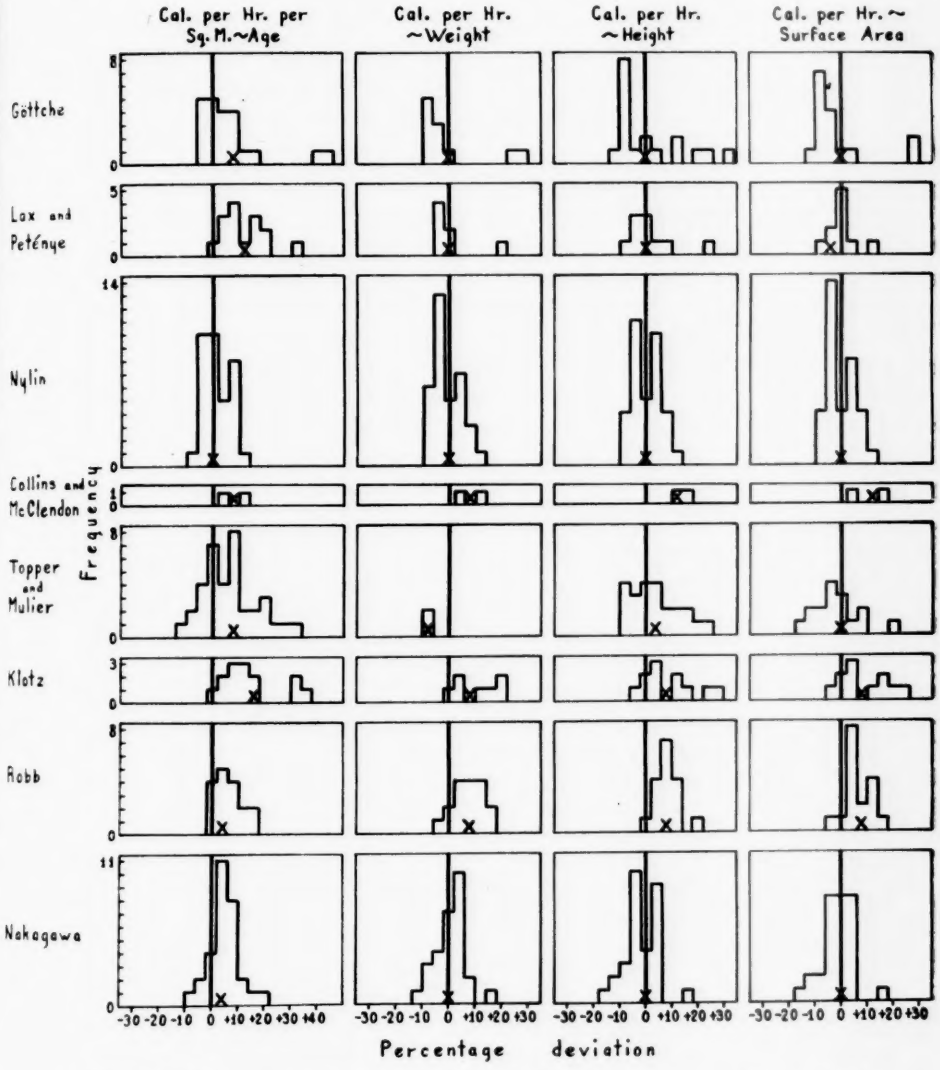

Fig. 16.—Histograms of the percentage deviations of the results on girls reported by the workers indicated on the chart from the central trend line values of the present study. × represents the mean percentage deviation with regard to sign.

Hendry are low and show mean percentage deviations with and without regard to sign of —8.3 and 8.3, respectively; those of Bedale, of —0.5 and 12.6, respectively, for boys and of +9.1 and 9.1, respectively, for

girls. It is difficult to interpret the values of Topper and Mulier [53] for girls, since a number of them fall outside the limits of the range for body surface, weight and height. The number of calories per hour per square meter of body surface in relation to age, the measurement by which the greatest number of tests are comparable, shows a mean percentage deviation of +6.9 with regard to sign and 9.5 without regard to sign. The results on the 3 Chinese girls observed by Benedict and

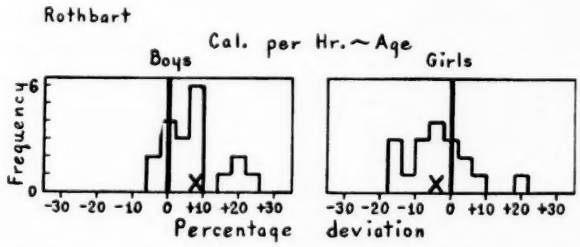

Fig. 17.—Histograms of the percentage deviations of the results reported by Rothbart [63] for calories per hour referred to age for boys and girls from the values of the unsmoothed lines connecting the means of the similar values of the present study. × represents the mean percentage deviation with regard to sign

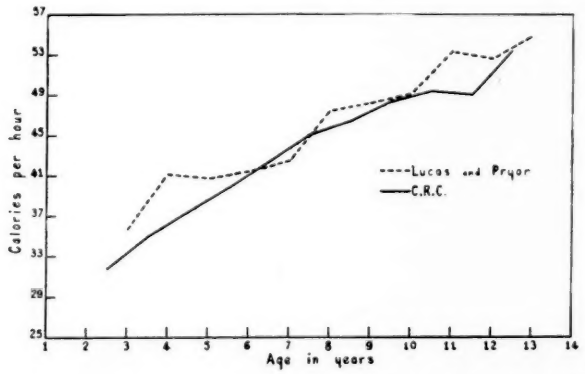

Fig. 18.—Comparison of the results of Lucas and Pryor [50] and those of the present study for boys expressed as calories per hour referred to age. The lines are unsmoothed and connect the means for the age panels. C.R.C. denotes Child Research Council.

Meyer [20] show mean percentage deviations with and without regard to sign for calories per hour per square meter in relation to age of +12.5 and 12.5, respectively, and for calories per hour in relation to body surface of —0.2 and 11, respectively.

The results of Rothbart [63] were compared with the corresponding values (taken from figures 18 and 19) of the unsmoothed lines con-

necting the means of the calories per hour in relation to age for the children of the present study. The frequencies of the percentage deviations are given in figure 17, and the mean percentage deviations with and without regard to sign are +6.5 and 7.8, respectively, for boys and —3.8 and 7.7, respectively, for girls.

Since the Kestner and Knipping [43] standards are multiple prediction standards in which the heat production is obtained from the height, weight and age of the subject, the standards cannot be compared directly with the values given in tables 17 to 20, inclusive. Instead, the result of each third satisfactory test on each subject in the present study was compared with the Kestner and Knipping prediction values and also with the values obtained in the present study for calories per hour per square meter of body surface in relation to age. This method of com-

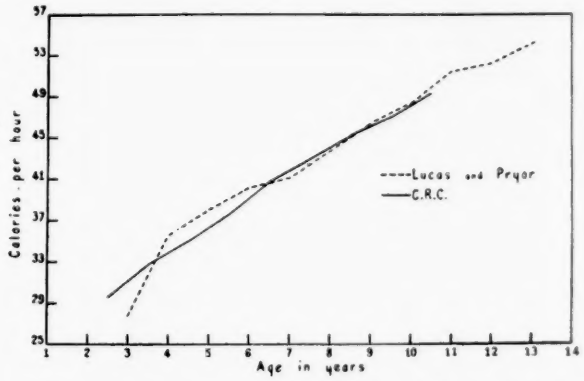

Fig. 19.—Comparison of the results of Lucas and Pryor [50] and those of the present study for girls expressed as calories per hour referred to age. The lines are unsmoothed and connect the means for the age panels. C.R.C. denotes Child Research Council.

parison was used because, like the Kestner and Knipping prediction standards, it takes into consideration the three factors, age, weight and height, and also because it gives a fairer sampling of the data than would be obtained from a similar number of tests chosen at random. The percentage deviation from the standard was calculated in each case, and histograms were made to show the frequencies of the deviations. The histograms are shown in figure 20. The mean percentage deviations, with and without regard to sign, for the Kestner and Knipping standards are +1.8 and 7.7, respectively, for the boys and —0.21 and 4.9, respectively, for the girls. In relation to the values obtained in the present study the mean percentage deviations, with and without regard to sign, are +0.63 and 5.4, respectively, for the boys and +0.46

and 4.0, respectively, for the girls. It appears that for the 93 tests involved the Kestner and Knipping standards predicted the basal metabolism well, although, as may be noted from the histograms, there is a slightly greater disperson with those standards than with the standards of the present study, particularly in the case of the boys.

It is evident that the mean percentage deviations with and without regard to sign, even in combination with the frequency charts, do not show the whole relationship of two sets of data in which one variable changes in reference to another, unless the central trends of the two are exactly the same. Figures 19 to 30, inclusive, show the central trends of the results published by Benedict and Talbot,[1] Talbot (1921,[23]

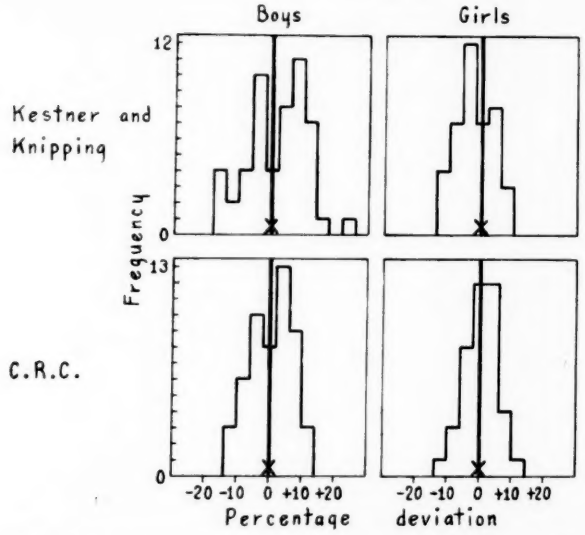

Fig. 20.—Histograms of the percentage deviations of the third satisfactory tests on the children of the present study from the values predicted by the Kestner and Knipping [43] standards and from the central trend line values of this study for calories per hour per square meter referred to age. × represents the mean percentage deviation with regard to sign.

1925 [24] and 1933 [15]), Talbot, Wilson and Worcester [25] (1935), Boothby and Sandiford,[34] Bailey,[35] Cameron,[31] Bierring,[42] deBruin,[57] and Lucas and Pryor [50] and those of the present study. Since the standards of Aub and Du Bois [82] are accepted as being too high for children from 2 to 12 years old, inclusive (Du Bois,[86] 1930), they were not charted.

The Benedict and Talbot [1] standards were found to be lower than those of many other workers, and this was attributed to the difference

86. Du Bois, E. F.: Recent Advances in the Study of Basal Metabolism, J. Nutrition **3**:217 (Sept.) 1930.

in experimental conditions under which they were established. Benedict and Talbot attempted to have all their subjects asleep when the tests were made. The actual amount of decrease in metabolism attributable to sleep is still under investigation. Wang and Kern [87] (1928) found that sleep lowered the metabolism from 5.7 to 30.6 per cent, with an average of 15 per cent. Mason and Benedict [88] found that in all cases the level of the heat production of 7 South Indian women and 2 western women was lower when they were asleep than when they were awake. The decrease varied between 4.1 and 15.5 per cent, with an average of 9.8 per cent for the Indian women and 7.1 per cent for the 2 western women. These authors said that a review of the work of Loewy,[89] Magnus-Levy,[90] Johansson,[91] Benedict,[92] Benedict and Carpenter,[93] Delcourt-Bernard and Mayer,[94] Pickworth,[95] Necheles [96] and Grollman [97] indicates a decrease of about 7 per cent. It was suggested by Mason and Benedict [88] and also by Wang and Kern [87] that the decrease varies

87. Wang, C. C., and Kern, R.: The Influence of Sleep on Basal Metabolism of Children, Am. J. Dis. Child. **36**:83 (July) 1928.

88. Mason, E. D., and Benedict, F. G.: The Effect of Sleep on Human Basal Metabolism, with Particular Reference to South Indian Women, Am. J. Physiol. **108**:377 (May) 1934.

89. Loewy, A.: Ueber den Einfluss einiger Schlafmittel auf die Erregbarkeit des Atemzentrums nebst Beobachtungen über die Intensität des Gaswechsels im Schlafe beim Menschen, Berl. klin. Wchnschr. **28**:437, 1891; cited by Loewy, in Oppenheimer, C.: Handbuch der Biochemie des Menschen, Jena, G. Fischer, 1911, vol. 4, pt. 1, p. 176.

90. Magnus-Levy, A.: Ueber die Grösse des respiratorischen Gaswechsels unter dem Einfluss der Nahrungsaufnahme, Arch. f. d. ges. Physiol. **55**:1 (July) 1894.

91. Johansson, J. E.: Ueber die Tagesschwankungen des Stoffwechsels und der Körpertemperatur in nüchternem Zustande und vollständiger Muskelruhe, Skandinav. Arch. f. Physiol. **8**:85, 1898.

92. Benedict, F. G.: Basal Metabolism: The Modern Measure of Vital Activity, Scient. Monthly **27**:5 (July) 1928.

93. Benedict, F. G., and Carpenter, T. M.: The Metabolism and Energy Transformations of Healthy Man During Rest, Publication 126, Carnegie Institution of Washington, 1910.

94. Delcourt-Bernard, E., and Mayer, A.: Recherches sur le métabolisme de base: III. Métabolisme de base et "repos"; A.—Cas de la thermorégulation, du jeûne, du sommeil, Ann. de physiol. **1**:536 (Aug.) 1925.

95. Pickworth, F. A.: Basal Metabolism as Determined by the Respiratory Exchange, Proc. Roy. Soc., London, s.B **101**:163 (March 1) 1927.

96. Necheles, H.: Basal Metabolism in Orientals, Am. J. Physiol. **91**:661 (Jan.) 1930; Ueber den Stoffwechsel der Chinesen: IV. Ueber den Niedrigen Grundumsatz und Methoden, Chinese J. Physiol. **6**:201 (May) 1932.

97. Grollman, A.: Physiological Variations in the Cardiac Output of Man: XI. The Pulse Rate, Blood Pressure, Oxygen Consumption, Arteriovenous Oxygen Difference, and Cardiac Output of Man During Normal Nocturnal Sleep, Am. J. Physiol. **95**:274 (Nov.) 1930.

with the depth of the subject's sleep. To compare their results on Chinese girls with those reported by Benedict and Hendry [18] on girl scouts, Benedict and Meyer [20] corrected the values for girl scouts on the assumption that sleep lowers the metabolism approximately 10 per cent. It seems evident from these reports and also from a few cases studied in this laboratory that tests made on sleeping subjects cannot be expected to predict satisfactorily the heat production of subjects who are awake. As the standards published by Benedict and Talbot [1] in 1921 and by Talbot in 1921,[23] 1925 [24] and 1933 [15] and the modification of these for girls reported by Talbot, Wilson and Worcester [25] in 1935 were based on tests made on both sleeping subjects and awake subjects and the proportion of each in the different groups is unknown, they cannot be satisfactorily used for comparison throughout the whole range of observation with tests made on subjects who are awake. Wang and Kern [87] found that their values agreed with the Benedict and Talbot standards more closely for sleeping subjects in the younger age groups and for subjects who were awake in the upper age groups. Lucas, Pryor, Bost, Pope and Henderson [48] found that these standards agreed with their own results more closely for the older than for the younger children. Accordingly, they suggested a +11.5 per cent correction of the Talbot standards for the preadolescent group (from 3 to 9 years of age) and a +1.4 per cent correction for the adolescent group (from 10 to 18 years of age) for calories per hour per square meter of body surface in relation to age.

The calories per hour in relation to weight and height, respectively, of the Benedict and Talbot series and of the present study agree more closely for the larger boys than for the smaller boys (figs. 21 and 22). The trend lines touch each other at 150 cm. and 35 Kg. The values for the girls run more nearly parallel than do those for the boys, with the Benedict and Talbot values approximately 11 per cent lower in both cases (figs. 23 and 24). The mean values reported by Benedict and Talbot that involve body surface cannot be compared with those of the present study, since the body surface of the subjects was determined by the Du Bois linear formula and the values are higher than if they had been computed by the same method as those of the present study, i. e., by the Du Bois height-weight formula.

The modified standards for girls published by Talbot, Wilson and Worcester [25] in 1935 are approximately 7 per cent lower than those of the present study when calories per hour in relation to weight are compared and for the region between 100 and 130 cm. of height when calories per hour in relation to height are compared (figs. 22 and 24). For the region between 84 and 100 cm. and between 130 and 146 cm. the agreement is closer than 7 per cent.

The standards of Boothby and Sandiford [34] and of Bailey,[35] both of which give calories per hour per square meter of body surface in relation to age, are approximately 8 and from 6 to 15 per cent, respec-

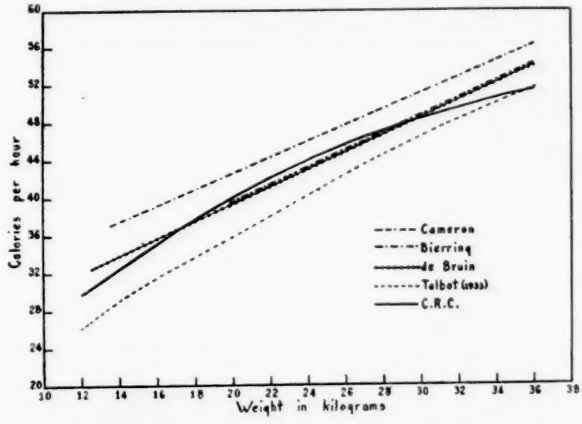

Fig. 21.—Comparison of the basal metabolism standards for boys reported by the workers indicated on the chart expressed as calories per hour referred to weight. The curve marked Talbot (1933) also represents the results reported by Benedict and Talbot [1] and by Talbot in 1921 [23] and 1925.[24] C. R. C. in this and the following figures denotes Child Research Council and designates the values of the present study.

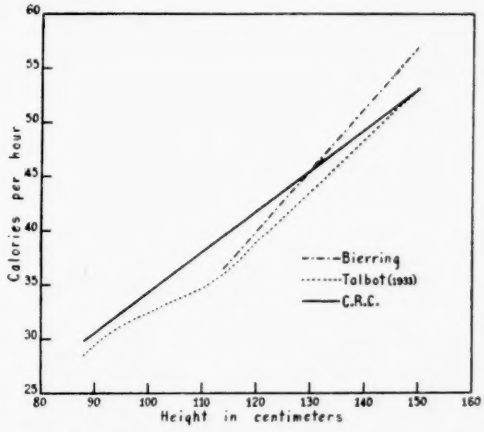

Fig. 22.—Comparison of the basal metabolism standards for boys reported by the workers indicated on the chart expressed as calories per hour referred to height. The curve marked Talbot (1933) also represents the results reported by Benedict and Talbot [1] and by Talbot in 1921,[23] and 1925.[24]

tively, higher than the results of the present study (figs. 25 and 26). The trends are not the same; the variation is greater in both cases for the higher age groups.

The trend of the heat production in relation to weight as published by Cameron [31] is a straight line. The values are somewhat higher than those of the present study in the case of the boys and of the smaller girls, but agree rather closely in the case of the larger girls (figs. 21 and 23).

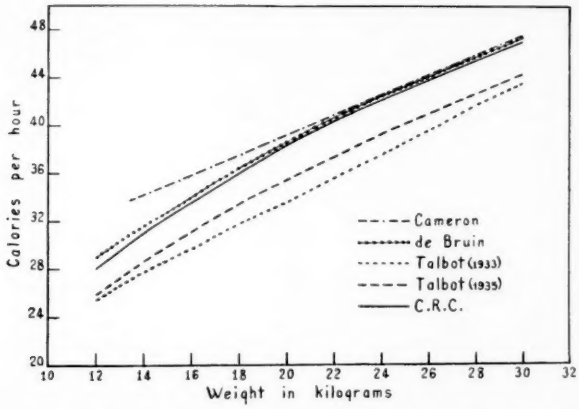

Fig. 23.—Comparison of the basal metabolism standards for girls reported by the workers indicated on the chart expressed as calories per hour referred to weight. The curve marked Talbot (1933) also represents the results reported by Benedict and Talbot [1] and by Talbot in 1921 [23] and 1925.[24] The curve marked Talbot (1935) indicates the results reported by Talbot, Wilson and Worcester.[25]

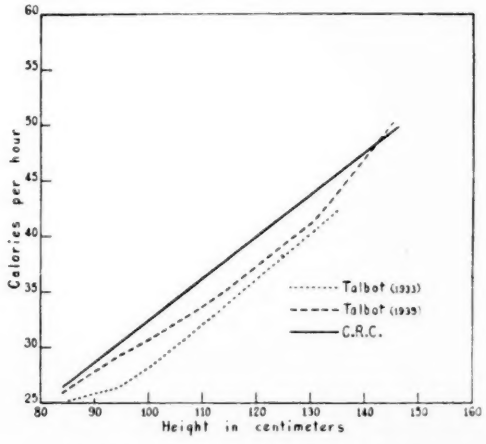

Fig. 24.—Comparison of the basal metabolism standards for girls reported by the various workers indicated on the chart expressed as calories per hour referred to height. The curve marked Talbot (1933) also represents the results reported by Benedict and Talbot [1] and by Talbot in 1921 [23] and 1925.[24] The curve marked Talbot (1935) indicates the results reported by Talbot, Wilson and Worcester.[25]

The general trends of the mean values reported by Bierring [42] for boys between the ages of 7 and 12 years, inclusive, and those of the present study are not the same (figs. 21, 22, 25 and 27). The differences vary with the several methods of expressing the heat production. In all cases except that in which the heat production was compared to height, there is a more marked variation for the upper age groups. The data of the present study are rather sparse for the older boys, and the

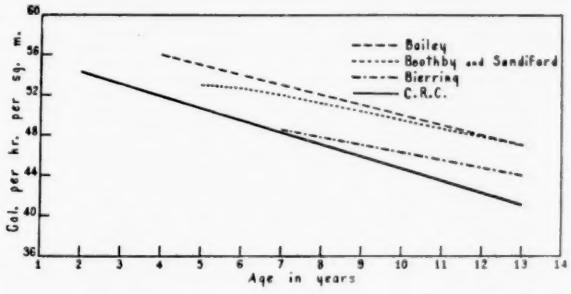

Fig. 25.—Comparison of the basal metabolism standards for boys reported by the workers indicated on the chart expressed as calories per hour per square meter referred to age.

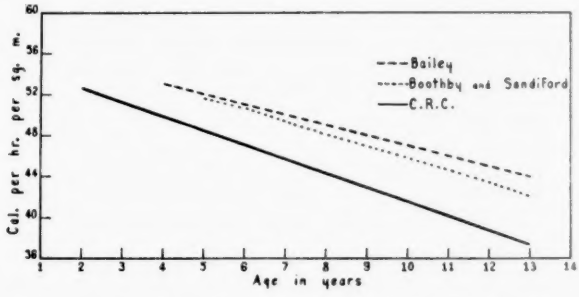

Fig. 26.—Comparison of the basal metabolism standards for girls reported by the workers indicated on the chart expressed as calories per hour per square meter referred to age.

accumulation of more data is to be desired before these differences can be discussed with satisfaction.

The results of de Bruin [57] for Dutch children show trends and levels that are for the most part close to those of the present study for calories per hour in relation to weight and body surface for girls (figs. 23 and 28). For boys the trends (figs. 21 and 27) are not the same, since those of de Bruin show a linear relationship and those of the present study do not. The greatest difference is in the region of the larger weights and larger surface areas. As has been emphasized in reference

to a similar difference in the values of Bierring for boys, more data are necessary for the larger children of the present study, both boys and girls, before the values for these groups can be accepted without reservation.

Figures 18 and 19 show unsmoothed lines connecting the means for calories per hour in relation to age reported by Lucas and Pryor [50]

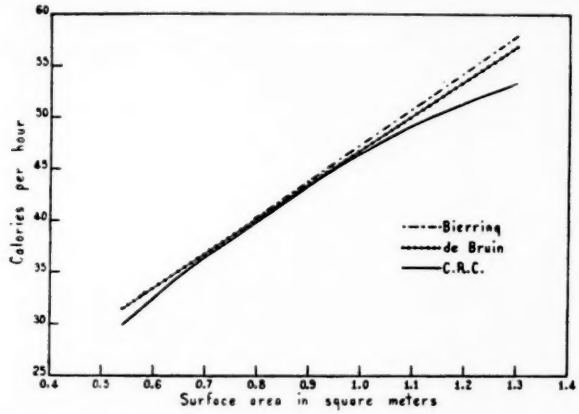

Fig. 27.—Comparison of the basal metabolism standards for boys reported by the workers indicated on the chart expressed as calories per hour referred to body surface.

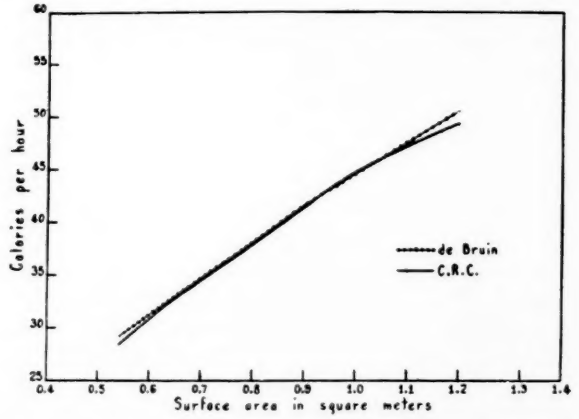

Fig. 28.—Comparison of the basal metabolism standards for girls reported by the workers indicated on the chart expressed as calories per hour referred to body surface.

and the unsmoothed lines connecting the similar means obtained in the present study. The two lines for girls are close together and appear to have the same trend, while those for boys are more irregular but

seem to agree rather closely for the region representing the ages between 6 and 10 years. Above and below this region, the agreement is doubtful. Figures 29 and 30 give a similar comparison for calories per hour per kilogram in relation to age. The trends and levels of the two lines for girls are the same for children between 9 and 10 years, but for those between 3 and 9 years the values of Lucas and Pryor are from 2 to 14 per cent lower than those of the present study. For the boys,

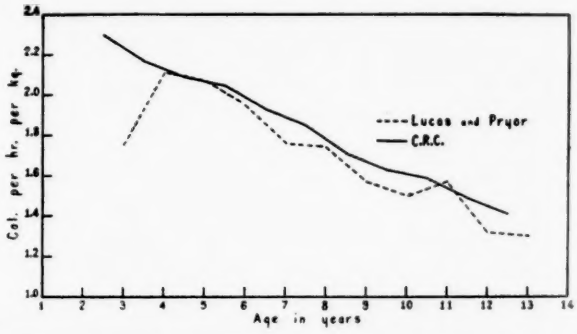

Fig. 29.—Comparison of the results of Lucas and Pryor [50] and those of this study for boys expressed as calories per hour per kilogram referred to age. The lines are unsmoothed and connect the means for the age panels.

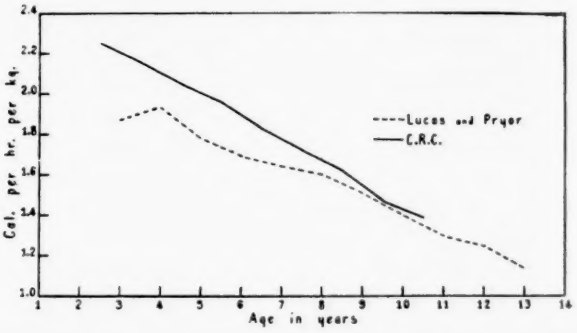

Fig. 30.—Comparison of the results of Lucas and Pryor [50] and those of this study for girls expressed as calories per hour per kilogram referred to age. The lines are unsmoothed and connect the means for the age panels.

the values of Lucas and Pryor appear to be only slightly lower than those of the present study for the whole age group.

Thus it appears that the results of Klein, Müller and Steuber,[27] Blunt, Tilt, McLaughlin and Gunn,[39] Bierring,[42] Nylin,[51] Collins and McClendon [52] on boys, Nakagawa [61] on Japanese children, Magnus-Levy and Falk [7] on girls, MacLeod,[32] Göttche,[41] Lax and Petényi,[45] Wang, Kern, Frank and Hays,[36] Wang and Hawks [37] on Chinese boys, Molitch

and Cousins,[58] Bedale [28] on boys, Rothbart [63] on girls, Lucas and Pryor,[50] Kestner and Knipping [43] and de Bruin [57] that are comparable to those of the present study substantiate in a degree the mean values as reported in tables 17 to 20, inclusive, and the observation that normal variation is within approximately ± 17 per cent from the mean. It is suggested that the deviations of the results of Magnus-Levy and Falk [7] on boys, Du Bois [12] on boys (minimum values), Talbot [22] on twin boys, Hobson,[29] Wang,[38] Bedale [28] on girls, Collins and McClendon [52] on girls, Topper and Mulier,[53] Benedict and Meyer [20] on Chinese girls, Rothbart [63] on boys and Wang and Hawks [37] on Chinese girls from the results of the present study may be attributed, at least in part, to the chance of selection, to differences in body proportions or to both these factors.

If this theory is accepted only the values reported by Benedict and Talbot,[1] Talbot [98] and Talbot, Wilson and Worcester [25] remain as lower than those of the present study and this difference has been explained in the foregoing discussion as due to the influence of sleep on energy metabolism. The values higher than those of the present study are the standards of Bailey,[35] Boothby and Sandiford [34] and Cameron [31] and the results reported by Talbot [22] for twin girls, Rosenblüth,[47] Klotz [54] and Robb.[59] It may well be that their results are higher than those of the present study because of differences in experimental conditions.

Since many of the results which agree with those of the present study were obtained by the use of the so-called clinical type of apparatus rather than by the chamber method used in this study, it appears that values obtained by these clinical methods for determining the basal metabolism do not vary significantly from those obtained by the chamber method, provided the same experimental conditions are maintained. Definite proof of this will be established when a series of experiments are made with both types of apparatus on the same subject during one experimental period.

By reference to table 23, it may be noted that the mean percentage deviations with regard to sign in all cases except those of Nylin [51] for boys, Collins and McClendon,[52] Talbot [22] in his study of twins, Hobson [29] and Robb [59] tend to be more positive when the values for calories per hour per square meter referred to age are compared than when the values for calories per hour referred to weight or the values for calories per hour referred to body surface are used. It is evident, also, from table 24 that the children used in the present study had a greater mean body surface for their age than the children, other than those previously mentioned, whose basal metabolism was compared from the standpoint of calories per hour per square meter referred to age. These

98. Talbot, footnotes 15, 23 and 24.

observations suggest the desirability and importance of complete anthropometric studies in conjunction with studies on basal metabolism.

Although the program of the Child Research Council includes a thorough anthropometric study, it is not the purpose of this paper to present complete anthropometric data, and only a few comments will be made regarding the relation of the body build to the basal metabolic rate. If the basal metabolic rate, expressed as percentage deviation from the mean, is calculated for a single subject by the different methods

TABLE 24.—*Mean Percentage Variations of the Mean Surface Area for Age of the Children Whose Basal Metabolism Was Compared as Calories per Hour per Square Meter of Surface Area Referred to Age from the Mean Surface Area for Age of the Children of the Present Study*

	Boys		Girls	
Author	Ages Represented, Years	Mean Percentage Variation	Ages Represented, Years	Mean Percentage Variation
Magnus-Levy and Falk	6, 7, 9, 10, 11	—16.0	7, 11,12	—25.7
Du Bois	12	— 8.3		
Benedict and Talbot	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	— 7.7	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	—11.6
Benedict and Hendry	.....	.....	12	— 7.9
Benedict and Meyer (Chinese)	.....	.....	12	—16.1
Talbot (twins)	2, 5, 12	—12.4	7, 10, 11	— 5.4
Klein, Müller and Steuber	7, 8, 9, 10	—10.8		
Hobson	9, 11, 12	+ 0.5		
MacLeod	.....	.....	10, 11, 12	— 1.8
Wang, Kern, Frank and Hays	.....	.....	4, 5, 8, 9, 10, 11	—13.2
Wang and Hawks (Chinese)	5, 7, 8, 9, 10, 11	—15.4	5, 6, 7, 9, 12	—20.2
Wang	.....	.....	12	—27.9
Blunt, Tilt, McLaughlin and Gunn	.....	.....	7, 8, 9, 10, 11, 12	— 3.8
Götteche	7, 8, 9, 10, 11, 12	—13.4	3, 6, 9, 10, 11, 12	—13.4
Lax and Petényi	.....	.....	10, 11, 12	—19.3
Rosenblüth	11, 12	— 0.8		
Nylin	4, 5, 6, 7	— 1.0	5, 6, 7	— 4.0
Collins and McClendon	3, 5	— 8.3	5	— 1.0
Topper and Mulier	11, 12	— 4.8	10, 11, 12	— 8.0
Bierring	7, 8, 9, 10, 11, 12	— 6.4		
Klotz	8, 11, 12	— 5.6	8, 11, 12	—14.2
Robb	3, 4	— 2.2	3, 4	+ 2.9
Nakagawa (Japanese)	3, 4, 5, 6, 7, 8, 9, 10, 11	—12.4	4, 5, 6, 7, 8, 9, 10, 11	—16.0

of referring the heat production, the resulting values vary from the normal to approximately the same degree irrespective of which method for the prediction of the metabolism is used, provided the height and weight of the child, and hence his body surface, are close to the means for the children in his age group with whom the standards were established. However, if his height, weight and body surface do not tend to approach the mean values for his age, the basal metabolic rates obtained by the several methods of referring the metabolism may differ considerably from one another. When these measurements vary from the mean but still fall within the limits of variation of the measurements

of the normal children used in the establishment of the standards, differences in the basal metabolic rates computed by the various methods may be found, although they are not greater than those found for some of the normal children used. Such differences are directly attributable to the body build and vary in degree with the discrepancies in the body measurements from the mean homologous measurements of the children with whom the standards were established. It seems obvious, then, that a certain amount of difference in the basal metabolic rates obtained by the several methods of reference is to be expected as a result of normal variation in body build and that this should be taken into consideration when the results by the different methods are compared.

Closely related to this question is that of the variation to be expected in the basal metabolic rates computed from the several methods of reference for the child of abnormal proportions. The preceding discussion, concerning the effect of normal variation in the body build on the values obtained for the basal metabolic rate by the different methods of reference, applies in even greater measure in the case of the child of abnormal proportions. Certainly more pronounced differences in the values obtained by the several methods are found in this case, and this raises the problem as to which of the methods of reference is most satisfactory for comparing the metabolism of a subject of abnormal proportions. Since a large number of cases of endocrine dysfunction are of this type, a solution of this question assumes great importance both to the clinician and to those who are charged with the determination of the basal metabolism. However, as its adequate treatment would involve an extensive statistical analysis of the results on children of abnormal proportions reported in the literature, no attempt will be made to discuss it in any detail here, and only a few general statements will be made. Since body build influences to such an extent the basal metabolic rates as computed by the several methods of reference, it is desirable to know whether the measurements of a child on whom a determination of the basal metabolism is being made fall within the limits of normality of the children with whom the standards were established. Accordingly the pertinent body measurements of the normal children are presented, so that they may be available for comparison with the similar measurements of the child under investigation. Tables 25 and 26 give the values for the mean, maximum and minimum height, weight and body surface for each age group of the boys and girls, respectively, of the present study. By reference to the proper table it may be determined whether the height, weight and body surface of the child for whom it is desired to use the standards of the present study fall within the normal range for his age group. If they do, any one of the three sets of central trend line values recommended as prediction standards—calories per hour per square meter referred to age (table 17), calories

per hour referred to weight (table 18) or calories per hour referred to body surface (table 19)—may be used equally satisfactorily for computing the basal metabolic rate. When the further collection of data warrants a comparative study of the anthropometric measurements and basal metabolism findings, it is hoped that a definite recommendation may be made concerning the procedure to be followed in calculating the basal metabolic rate of children whose measurements fall outside the

TABLE 25.—*Mean, Maximum and Minimum Values for the Surface Area (Du Bois and Du Bois [84] Height-Weight Formula, with Constant 71.84), Weight and Height for the Various Age Groups of the Boys of the Present Study*

Age, Years	Weight, Kg.			Height, Cm.			Surface Area, Sq. M		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
2- 3	13.9	16.4	12.0	93.3	98.5	86.9	0.589	0.645	0.525
3- 4	16.2	19.4	14.2	100.6	107.3	95.7	0.665	0.750	0.610
4- 5	18.0	22.2	14.9	108.2	119.4	101.0	0.730	0.860	0.650
5- 6	19.5	24.7	15.9	114.6	128.3	107.3	0.790	0.945	0.700
6- 7	22.3	29.6	16.7	122.3	134.2	113.0	0.873	1.040	0.730
7- 8	24.6	34.8	18.3	127.1	136.8	116.2	0.935	1.150	0.800
8- 9	27.5	40.8	20.5	131.6	143.8	119.4	1.005	1.275	0.855
9-10	30.2	44.2	23.9	136.1	147.8	125.3	1.072	1.335	0.920
10-11	31.2	42.6	26.4	140.1	148.2	128.5	1.112	1.305	0.970
11-12	33.1	42.3	28.4	146.2	153.5	137.6	1.176	1.310	1.070
12-13	38.2	51.9	31.8	151.4	162.5	144.3	1.282	1.540	1.160

TABLE 26.—*Mean, Maximum and Minimum Values for the Surface Area (Du Bois and Du Bois [84] Height-Weight Formula, with Constant 71.84), Weight and Height for the Various Age Groups of the Girls of the Present Study*

Age, Years	Weight, Kg.			Height, Cm.			Surface Area, Sq. M.		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
2- 3	13.2	15.5	10.2	92.3	100.9	84.0	0.571	0.640	0.480
3- 4	15.2	17.8	12.0	100.3	109.8	93.4	0.646	0.735	0.565
4- 5	17.2	20.8	12.6	106.8	118.7	98.8	0.709	0.830	0.595
5- 6	19.4	23.9	14.2	113.9	125.3	104.1	0.783	0.915	0.645
6- 7	22.6	29.8	16.2	122.0	131.5	111.8	0.878	1.030	0.715
7- 8	25.2	33.7	18.1	128.1	139.0	116.6	0.952	1.145	0.775
8- 9	28.4	38.0	21.8	133.6	144.4	122.4	1.031	1.240	0.865
9-10	32.3	40.7	25.4	138.5	147.0	130.3	1.120	1.296	0.970
10-11	35.6	41.3	29.3	145.1	153.2	137.9	1.207	1.330	1.105
11-12*									
12-13*									

* Values not computed if less than 10 tests were made for group.

range of those of the children with whom the standards were established. Until such a correlated study has been attempted it is suggested that all three sets of standards—calories per hour per square meter referred to age (table 17) and calories per hour referred to weight and body surface, respectively (tables 18 and 19)—be given consideration.

Since the upper age limit for the children reported on in this paper is 12 years, the question of prepubertal rise in the basal metabolism of children cannot be discussed from the standpoint of this group of children.

The question of the effect of altitude on the basal metabolism arises, since the altitude of Denver is approximately 5,280 feet. Several studies have been made in the past to determine any relationship between the partial pressure of the oxygen in the surrounding atmosphere and the basal metabolism. In 1909 Durig [99] analyzed all the data available in the literature of the various Alpine expeditions and concluded that in the majority of persons the gaseous exchange had increased at altitudes of from 6,600 to 15,000 feet. In 1916 Krogh [100] stated that the results of several workers showed that with an atmospheric pressure greater than 410 mm. of mercury (partial pressure of oxygen, 83 mm.) the tension of oxygen in the capillaries remains constant and that there is no reason to believe that with a constant supply of oxygen the absorption of oxygen, also, should not remain constant. In 1924 Schneider, Truesdell and Clarke,[101] by the use of the low pressure chamber at Mitchell Field, found a tendency to lowered metabolism with a decrease in the partial pressure of oxygen in unacclimated subjects, but they stated in the same paper: "In this series of experiments we believe we have obtained evidence that proves the reduction in the oxidative processes of the body to be only temporary. In some individuals the metabolism soon returns to normal; while in others, as discomfort and evidences of 'mountain sickness' appear, it rises above normal." In 1925 Schneider and Clarke [102] stated that in studying muscular exercise under low barometric pressure they made determinations of the basal metabolism prior to the other observations and that the results supported the conclusion of the 1924 series "to the effect that the oxidative processes of the body are retarded at barometric pressures less than 410 mm." Since the barometric pressure during the present study ranged between 610 and 645 mm. of mercury and the partial pressure of the oxygen in the chamber was never below 120 mm. of mercury, it seems permissible to conclude that the basal metabolism of the 93 acclimatized normal children for whom results have been reported in this paper was not influenced by the low partial pressure of the oxygen supply.

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SUMMARY AND CONCLUSIONS

As a report of progress in a longitudinal study of normal children, the results of 366 basal metabolism tests on 52 boys and of 271 basal metabolism tests on 41 girls, all between the ages of 2 and 12 years, inclusive, are presented. The tests were made by means of the open circuit chamber method and the Carpenter-Haldane gas analysis apparatus.

The results are presented in a cross-sectional manner, and the heat production is expressed as calories per hour referred to age, weight, height and surface area, respectively, and as calories per hour per square meter of surface area, calories per hour per kilogram of body weight and calories per hour per centimeter of total height, respectively, referred to age.

The means, the standard deviations from the means and the coefficients of variation of the observed heat production for convenient arbitrary divisions of the variable to which the heat production was referred were computed for each of the specified methods of expressing the energy metabolism.

The mean coefficient of variation, a statistic which was used to indicate the degree of scatter of the individual tests, was found to be of increasing value in the following order:

Boys

1 and 2. Calories per hour referred to surface area
and
Calories per hour per square meter referred to age
3. Calories per hour referred to weight
4. Calories per hour referred to height
5. Calories per hour per centimeter referred to age
6 and 7. Calories per hour referred to age
and
Calories per hour per kilogram referred to age

Girls

1. Calories per hour referred to weight
2. Calories per hour per square meter referred to age
3. Calories per hour referred to surface area
4. Calories per hour per centimeter referred to age
5. Calories per hour referred to height
6. Calories per hour referred to age
7. Calories per hour per kilogram referred to age

This treatment of the data indicates that for the group of normal children under investigation three of the methods of expressing heat production, calories per hour referred to weight and surface area,

respectively, and calories per hour per square meter referred to age, give the lowest degrees of dispersion.

The mean coefficients of variation for these three methods show that theoretically 99.7 per cent (the percentage included within plus and minus three standard deviations from the mean) of all the tests should fall within ± 18 per cent of the mean for the boys and within ± 16 per cent for the girls and that 95 per cent (the percentage included within plus and minus two standard deviations) should fall within ± 12 per cent for the boys and within ± 11 per cent for the girls.

Scatter diagrams for these three methods and for calories per hour referred to height were constructed, and in each case the central trend line was fitted either by the semiaverage method or by inspection.

The central trend line values for calories per hour per square meter referred to age (table 17) and for calories per hour referred to weight and to body surface, respectively (tables 18 and 19), were tabulated in order that they might be available as prediction standards.

Even though they show somewhat greater dispersion than is the case with the three methods just mentioned, the central trend line values (table 20) for calories per hour referred to height were also tabulated, since this method of expressing the heat production has found rather wide use in the literature.

The relationship of the results of the present study to those reported by other workers was studied in detail by comparing the separate tests reported in the literature with the four central trend line values mentioned. Histograms of the percentage deviations were constructed. In cases in which the separate tests were not reported, the trends and levels of the results are shown graphically. The comparative results are discussed in detail.

This analysis of the results of basal metabolism tests on children reported in the literature demonstrates the significant effect of body build on the comparative values obtained for the basal metabolic rate by the several methods of reference. The importance of considering the relationship between the body measurements of the children for whom the standards are to be used and the homologous measurements of the children with whom they were established is emphasized thereby.

The precise relationship of body build to the basal metabolism of children cannot be determined until a more complete statistical study in close correlation with anthropometric and other physiologic measurements is made. Such an analysis will be warranted only when a larger collection of data is available.

Since the Child Research Council project is a longitudinal study designed to extend over a period of many years, additional data on the basal metabolism of children are constantly being accumulated, and further reports for the age groups represented in the present paper and for older and younger children may be expected in the future.